INERTIAL CONFINEMENT

FUSION

UCRL-ID-129037

1996

ICF

Program

Overview

Lawrence Livermore
National Laboratory

Distribution Category UC-712
October 1995–September 1996

Printed in the United States of America
Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, Virginia 22161
Price codes: printed copy A03, microfiche A01.

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Work performed under the auspices of the U.S. Department of Energy
by the Lawrence Livermore National Laboratory under Contract W-7405-Eng-48.

FOREWORD

The *ICF Program Overview* provides documentation of the achievements of the LLNL ICF Program during the fiscal year by the use of a narrative summary of important results. Both the *Overview* and the *ICF Quarterly Report* are also on the Web at http://lasers.llnl.gov/lasers/pubs/icfq.html.

The underlying theme for LLNL's ICF Program research is defined within DOE's Defense Programs missions and goals. While in pursuit of its goal of demonstrating thermonuclear fusion ignition and energy gain in the laboratory, the ICF Program provides research and development opportunities in fundamental high-energy-density physics and supports the necessary research base for the possible long-term application of inertial fusion energy for civilian power production. ICF technologies continue to have spin-off applications for additional government and industrial use.

LLNL's ICF Program falls within DOE's national ICF program that includes the Nova and Beamlet (LLNL), OMEGA (University of Rochester Laboratory for Laser Energetics), Nike (Naval Research Laboratory), and Trident (Los Alamos National Laboratory) laser facilities. The Particle Beam Fusion Accelerator and Saturn pulsed power facilities are at Sandia National Laboratories. General Atomics, Inc., develops and provides many of the targets for the above experimental facilities. Many of the *Quarterly Report* articles are co-authored with colleagues from these other ICF institutions.

Questions and comments relating to the content of this report should be addressed to the ICF Program Office, Lawrence Livermore National Laboratory, P.O. Box 808, L-488, Livermore, CA 94551.

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CONTENTS

ICF PROGRAM OVERVIEW

Introduction

The continuing objective of the Inertial Confinement Fusion (ICF) Program is the demonstration of thermonuclear fusion ignition and energy gain in the laboratory. The underlying theme of all ICF activities as a science research and development program is the Department of Energy's (DOE's) Defense Programs (DP) science-based Stockpile Stewardship and Management (SSM) Program. The extension of current program research capabilities in the National Ignition Facility (NIF) is necessary for the ICF Program to satisfy its stewardship responsibilities. ICF resources (people and facilities) are increasingly being redirected in support of the performance, schedule, and cost goals of the NIF.

One of the more important aspects of ICF research is the national nature of the program. Lawrence Livermore National Laboratory's (LLNL's) ICF Program falls within DOE's national ICF Program, which includes the Nova and Beamlet laser facilities at LLNL and the OMEGA, Nike, and Trident laser facilities at the University of Rochester (Laboratory for Laser Energetics, UR / LLE), the Naval Research Laboratory (NRL), and Los Alamos National Laboratory (LANL), respectively. The Particle Beam Fusion Accelerator (PBFA) and Saturn pulsed-power facilities are at Sandia National Laboratories (SNL). General Atomics, Inc. (GA) develops and provides many of the targets for the above experimental facilities.

LLNL's ICF Program supports activities in two major interrelated areas: (1) target physics and technology (experimental, theoretical, and computational research); and (2) laser science and optics technology development. Experiments on LLNL's Nova laser primarily support ignition and weapons physics research. Experiments on LLNL's Beamlet laser support laser science and optics technology development.

In addition, ICF sciences and technologies, developed as part of the DP mission goals, continue to support additional DOE objectives. These objectives are (1) to achieve diversity in energy sources through inertial fusion energy (IFE) research and (2) to maintain a competitive U.S. economy through new development of technologies of interest for government and industrial use, including Laboratory Directed Research and Development (LDRD).

This Overview is divided into sections that include Target Physics and Technology, Laser Science and Optics Technology, the National Ignition Facility, and Inertial Fusion Energy / New Technologies. These sections summarize the findings within the many articles written for refereed journals and the *ICF Quarterly Report*, and also discuss important results from FY 1996 that have not been covered explicitly in the articles.

Target Physics and Technology

The activities of the Target Physics and Technology (TP&T) Program are directed to ensure the success of achieving ignition on the NIF and supporting the science mission of the DP SSM Program. The activities fall into the following three main areas: Nova target physics, NIF target design and code development, and NIF target area technology development. In the FY 95 annual report overview, we reported that the DOE's Inertial Confinement Fusion Advisory Committee (ICFAC) had achieved its major target physics mission objective. This was a result of the following factors: (1) the Nova Technical Contract (NTC) was essentially completed; (2) there had been significant progress in establishing a robust target design for the NIF; and (3) major progress had been made in achieving adequate target surface finish of cryogenic ignition targets. During 1996, the TP&T Program has shifted its emphasis to better ensure successful ignition on the NIF and expand support for the DP SSM Program. The following is a brief summary of activities in these areas during FY 1996.

Nova Target Physics

Target Ignition Physics. Experiments and analyses continued in plasma physics, hohlraum physics, and high-growth-factor implosions. Much of the effort was devoted to extending quantitative understanding of the physics beyond the NTC and to better define the limits in target performance for the NIF. In addition, initial indirect-drive experiments were done on the Omega laser at UR (in collaboration with scientists from LANL and LLE) in order to determine the feasibility of using the facility for indirect drive.

Plasma physics experiments continued to investigate stimulated scattering processes in NIF-like plasmas using “gas-bag” and gas-filled “scale 1” Nova hohlraum targets. An extended set of experiments were done using the f/8 lens in beamline 7 to approximate the NIF focusing geometry. These experiments demonstrated an anticorrelation between stimulated Raman scattering (SRS) and stimulated Brillouin scattering (SBS) as a function of plasma density. This trend is seen in Fig. 1, which shows the SBS and SRS as a function of plasma densities. The data are from gas-bag targets using NIF focusing conditions of 0.35-μm light focused to intensities of 2×10^{15} W/cm^2 using an f/8 lens. Scattering levels have a weak but measurable dependence on smoothing by spectral dispersion (SSD) laser bandwidth as shown in Fig. 1. In addition, a new Thomson scattering diagnostic has been activated during the past year. Initial experiments using the probe during the past year measured temperature and density from gas-filled hohlraums. During the upcoming year, a new 4ω probe will be activated to extend the capability to higher density.

The principal activity for understanding symmetry in gas-filled hohlraums was to manufacture ten kinoform phase plates (KPP) to perform hohlraum coupling and symmetry experiments with ten smooth beams. Experiments in the previous year using one beam with a random phase plate (RPP) showed that the beam performed much closer to expectation than an unsmoothed beam. During this past year, a KPP design was developed to produce approximately round spots on the hohlraum wall. A single KPP was manufactured. Figure 2 shows the improvement of the beam spot at the equivalent plane of the laser entrance hole with a KPP compared to a Nova beam without smoothing. In single-beam experiments, the KPP performed similarly to the RPP in showing SBS and SRS. The thermal x-ray emission is similar to the calculated emission pattern. Manufacture of KPPs for the rest of the Nova beams is in progress and experiments will be done in 1997.

Most of the progress made in high-growth-factor implosions was in the area of analysis to understand the difference in predictions and calculations of the neutron yield for implosions with capsules having a good quality surface finish. Using the new capabilities in the 3-D code HYDRA, the effects of low-mode capsule asymmetry coupling to intrinsic hohlraum asymmetry were investigated. The coupling of these effects was shown to reduce the neutron yield more than if the two effects were assumed to be independent. Work continues to apply these capabilities in understanding the experiments.

We performed two weeks of indirect-drive experiments on the Omega laser at UR in collaboration with UR and LANL scientists. These were the first indirect-drive experiments performed in the facility. The experiments showed that indirect-drive experiments could successfully be fielded on Omega. Drive and implosion symmetry experiments were conducted similar to those conducted on Nova. These demonstrated that Omega can produce similar irradiation conditions as Nova when operated at similar power levels.

High-Energy-Density Stockpile Science Experiments. The ICF Program and scientists in LLNL’s A Division, B Division, V Division, and H Division continued to collaborate on high-energy-density stockpile science expieriments on Nova in FY 96.

Nova can produce a range of radiation temperature and pulse length capabilities for driving SSM-based

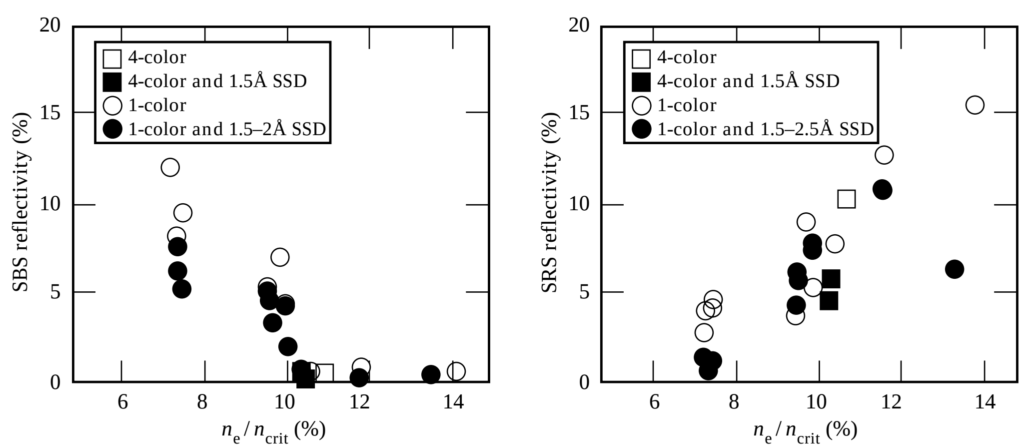

FIGURE 1. A scaling of (a) SBS and (b) SRS reflectivity as a function of plasma density for various laser conditions. The data are taken on Nova with one beam approximating NIF focusing conditions of 2×10^5 W/cm^2 of 0.35-μm light using an f/8 lens.
(02-25-0397-0478pb01)

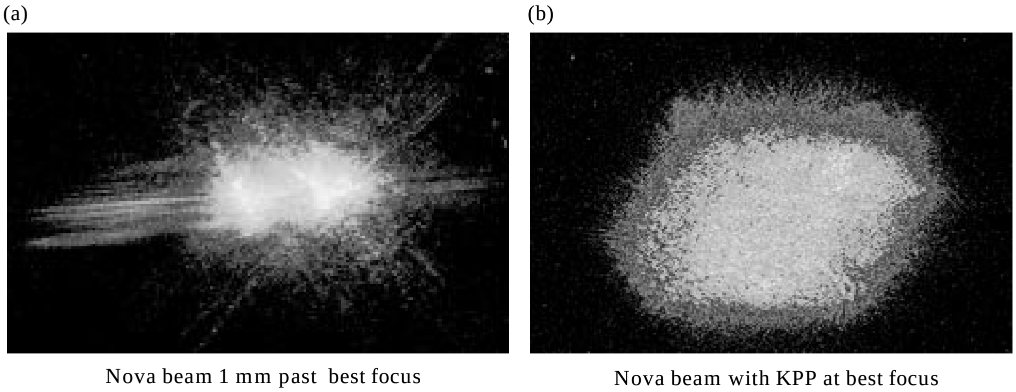

FIGURE 2. Far-field images of a Nova beam comparing the beam structure of a normal Nova beam (a) with one having a kinoform phase plate (b). (02-25-0397-0476pb01)

experiments and these capabilities can be scaled to the NIF. During this period, a collaboration between V & A Divisions and the ICF Program demonstrated that very-high-temperature hohlraums can be produced with hohlraums scaled down to a smaller size than the Nova scale 1, which is 2.6 mm length by 1.6 mm diameter. At the other extreme, a radiation temperature of >80 eV was produced for 14 nsec in a scaled-up hohlraum. The technique used for producing a long laser pulse was to stagger the 2-ns laser pulses. This capability has been used to produce drives for radiation flow experiments down gas-filled tubes where the position of the radiation front was measured by soft x-ray emission. These experiments complement similar experiments at SNL on their z-pinch sources. For the NIF longer pulses, close to 100 ns at 100 eV could be produced. At intermediate pulse lengths, ablation pressures of ~40 Mbar have been produced with 3% uniformity over scale lengths of up to 1 mm.

In collaboration with B Division, experiments have begun on Nova which measure the growth of hydrodynamic instabilities and equations of state in the presence of material strength. At pressures of ~1 Mbar, the melt temperature of metals increases up to 1 eV at compressions of 2–3 in accord with the Lindemann melt model. By carefully shaping the drive pulse on Nova, with a foot / pulse ratio of 50, we have been able (in calculations) to keep the shock heating of metals such as Cu and Mo below their melt temperature. The growth of Rayleigh–Taylor instability at a buried interface has been measured under these conditions, and a reduction in the growth rate because of strength in the solid state has tentatively been identified.

We have developed a plan to further investigate primary physics. We have preliminary data on the Bragg diffraction from a shocked Si witness plate showing lattice compression and subsequent expansion due to the rarefaction wave. The material stayed solid with a clearly defined Bragg diffraction. We have developed a Michelson interferometer to measure the expansion of the rear surface of a witness plate and, importantly, the expansion due to preheat.

We have worked with A Division and improved our understanding of the physics models used for hydrodynamic mixing in our computer simulations. Passive tracer layers with higher x-ray absorption than the surrounding plastic, so the position of the layer shows up on the radiographs, have been developed to investigate highly vertical flows in the regime between laminar and turbulent flow on Nova. In further hydrodynamic experiments, integrated laser-driven experiments have been used for improved understanding of the physics of thermonuclear secondaries.

In FY 96, Nova was used to make equation-of-state (EOS) measurements of cryogenic deuterium with sufficient precision to distinguish between an old EOS and a new EOS with energy loss from disassociation included. The EOS of hydrogen and its isotopes at high pressure have long been of interest, driven by the need for understanding the physics of high-density matter. Two applications, solar science and inertial confinement fusion (ICF), are critically dependent on hydrogen EOS behavior. The performance of deuterated ICF capsules relies on shock timing and efficient compression which are dependent on the EOS. For these reasons, a number of theoretical models of the EOS of hydrogen have been proposed. An important and outstanding question in the EOS of H_2, as well as D_2, has been the transition from a diatomic to a monatomic fluid. A continuous dissociative transition has been suspected but not observed. Theoretical predictions of molecular dissociation have been complicated by the presence of electronic transitions and possible ionization near pressures required for dissociation (~100 GPa). During this year we performed and published results of the first measurements of density, shock speed, and particle speed in liquid (cryogenic) deuterium, compressed by laser-generated shock waves to pressures from 25 to 210 GPa (0.25 to 2.1 Mbar). The data shown in Fig. 3 indicates that the D_2 compressibility above 50 GPa is significantly greater compared to the existing widely used equation of state. The data strongly indicate a continuous molecular dissociation transition of the diatomic fluid into a monatomic phase.

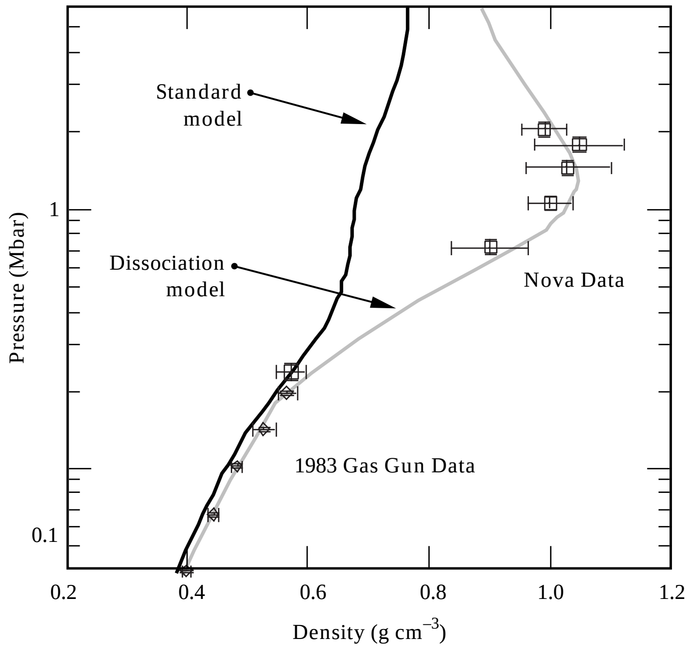

FIGURE 3. Data for the equation of state for liquid D_2 taken using Nova. The data are compared with the standard model (solid line) and the dissociation model (gray line). The previous gas gun data could not discriminate between the two models. (08-00-0996-2169pb01)

Advanced Concepts. The fast ignitor concept uses short-pulse lasers to produce fast electrons to heat a compressed core of DT fuel. Experiments to test the feasibility of this concept were done using the 100-TW laser in the 2-beam chamber of Nova. In 1996, experiments with 0.4-ps pulses at 2×10^{19} W/cm^{-2} demonstrated more than 20% efficiency of coupling laser energy to fast electrons. Modeling indicates that the internal coupling efficiency could be as high as 50%. In parallel, the Petawatt laser was demonstrated (as noted below), and the target chamber is being readied for target experiments in 1997.

NIF Target Design and Code Development

NIF Target Design. Work continued on the NIF point design robustness by direct 2-D simulation (using LASNEX) of inner DT surface and outer CH surface perturbations, coupled with low-mode (ℓ<10) capsule nonuniformities, driven by P_0 through P_8 drive/asymmetry spectrum extracted from integrated (hohlraum + capsule) LASNEX simulations, plus random, time-varying perturbations to that drive and asymmetry. With surface smoothness achieved to date in the laboratory, the capsules in these “everything on it” simulations ignited and burned giving nearly 1-D yields.

We further confirmed NIF robustness by running simulations in 3D using the HYDRA code (including thermonuclear burn physics) that combined inner and outer surface perturbations, with surface smoothness achieved to date in the laboratory. These too ignited and burned, giving nearly 1-D yields.

There was a redesign of the NIF point design to obtain more margin against high-mode (ℓ=100) mode perturbations, which if initially large enough, might break up the shell during the time period prior to achieving maximum velocity. (Current Nova target surface finishes have ℓ=100, smooth enough to meet the NIF specifications even prior to this redesign.) Simulations have also indicated that much higher modes are not an issue.

We designed a wider variety of NIF ignition capsules including lower-energy, lower-intensity 250-eV Be ablator capsules that should be safer from a laser plasma instability point of view. An ignition design was developed using a B_4C ablator.

We identified a beam arrangement on NIF that allows the baseline hohlraum geometry as well as tetrahedral hohlraum and direct-drive, and with LLE, identified a direct-drive ignition target design for NIF.

Code Development and Theory. The capsule-only 3-D radiation hydrodynamics code HYDRA has had a thermonuclear burn package added to it. Thus, in addition to analyzing Nova HEP4 implosions and the effects of low-mode capsule asymmetry coupled to the imposed Nova hohlraum drive asymmetries, it has now been applied to the study of yields for the NIF ignition capsule, subject of the evolution of 3-D inner and outer surface perturbations.

The more general purpose 3-D radiation hydrodynamics ICF design code of the future is HED3D, which will use many of the physics modules that have been developed as part of its precursor project, ICF3D. During this past year, the speed of the ICF3D hydrodynamics has increased considerably. Figure 4 shows an example of its capability in a 3-D calculation of the growth rate of a Rayleigh–Taylor instability. Moreover, its robustness and portability was successfully demonstrated by the fact that it ran on the IBM massively parallel “ASCI Blue Pacific initial delivery” machine within one day of delivery to LLNL. Within two days, a 2-D movie of a finely resolved Rayleigh–Taylor growth simulation was produced using 128 processors. In this past year, 3-D Rayleigh–Taylor growth test problems were successfully performed, with an under 2% error versus the analytic growth rate. PYTHON, a new computer science “shell” well-suited for a C++ object-oriented programming code such as HED3D, has been identified for use in the development of HED3D.

The development phase of the plasma code ZOHAR was completed this year. It is a fluid electron particle ion version of the 2-D fully PIC ZOHAR code. It has already been used to do initial studies of nonlinear saturation behavior of Brillouin scattering including

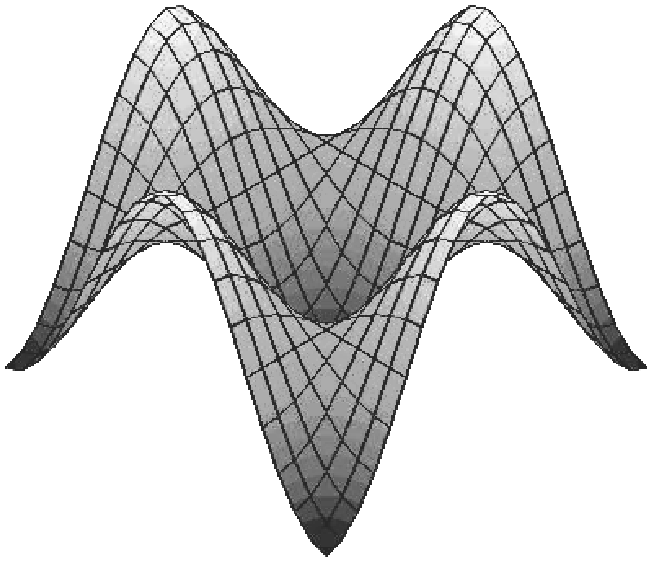

FIGURE 4. Example of the calculation of a Rayleigh–Taylor instability calculation using ICF3D. The figure shows an isodensity contour after perturbation growth. (08-00-0996-2163pb01)

effects of 2-D versus 1-D ion-wave-coherence collapse, as well as revealing interesting physics of the role of separate ions in the development of saturation effects for multispecies plasmas.

The hydrodynamics in the laser filamentation and propagation code F3D was made fully nonlinear. This has been an important development in its use to analyze high-intensity issues encountered in the analysis of high-temperature hohlraums. Figure 5 shows the nonlinear propagation of a laser beam breaking up into multiple filaments. Other developments involve the initial attempts at including into F3D models of the Raman-Brillouin scattering instability competition.

NIF Target Area Technology

NIF Diagnostics. NIF diagnostic developments concentrated on neutron diagnostics compatible with expected NIF yields. A Cherenkov radiation from 16.7 MeV (D,T) fusion gammas was observed as part of a burn history diagnostic capable of operation with NIF yields, requiring a long stand-off distance. An energy-resolved prototype is under construction. Monte Carlo analysis and design of the neutron shield for a proton-recoil neutron yield diagnostic was completed and a prototype is under construction. A charged-particle spectrometer was designed in collaboration with MIT. Preliminary experiments on track detection of charged particles from Nova experiments were completed with assessment of background levels, and a prototype spectrometer is under construction. In addition, a Neutron Time of Flight system was designed and is under construction at LLE (Rochester) for yield and ion-temperature measurement. This instrument will be remotely operable from LLNL. The Neutron Coded Aperture Imager experiment is being moved to LLE for completion.

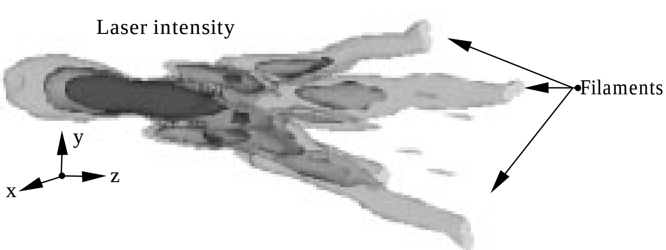

FIGURE 5. Example of a calculation from F3D. The figure shows a constant laser intensity profile for the case where the beam divides into several filaments. (08-00-0896-1888pb01)

NIF Ignition Capsules. Research continued on developing the technology for a variety of NIF ignition capsules. The ability to produce NIF-thickness, gas-permeable, seamless Be ablator coatings on plastic microshells by sputtering was demonstrated, and improvements in surface finish are under development. A technique has been developed and transferred to General Atomics that provides capsules with very small P_1 defects. This technology produces a thin plastic shell that can be decomposed and diffused through an overcoating. This is also the technique for producing all of the thin capsules for the LLE experiments. Optically transparent, 2-mm-diameter, low-density (60 mg/cm^3) foam shells with 100-µm wall, capable of holding liquid cryogenic D-T, were manufactured as an alternative ignition capsule. An LLNL contract with the Lebedev Institute in Moscow has resulted in the first production of 2-mm-diameter plastic shells by a drop tower technique. Improvements in surface finish are necessary.

Cryogenic Technologies. All NIF target designs require smooth cryogenic layers of DT as the inner capsule layer. In 1996, we completed and demonstrated a self-contained DT source for cryogenic target development experiments at LLNL. We demonstrated the efficacy of heat fluxes on smoothing of solid hydrogen in curved geometries with the same radius of curvature as NIF ignition capsules. For unheated “native” cryogenic layers, surface finishes required for ignition were demonstrated. We demonstrated the efficacy of producing heat fluxes in the interior of enclosed solid D-T cells by microwave heating the free charges in the vapor space and establishing the smoothing properties of this heat flux. We demonstrated the efficacy of infrared heating of bulk solid hydrogen for smoothing the surfaces. In addition, we designed and analyzed thermal characteristics of cryogenic hohlraums for beta-layering fuel in ignition capsules and are nearing completion of a cryogenic test system for development of cryogenic hohlraums.

NIF Target Chamber. Technology is being developed for the survivability and maintainability of the integrity of the NIF target chamber. We confirmed that B_4C can provide for x-ray protection of the chamber wall for up to 20-MJ yield, with only a few grams total ablation and thus minimal impact on debris shields. Figure 6 show the dramatic reduction of material removal for B_4C as a function of x-ray fluence compared to Al, the NIF chamber material. We improved modeling of vapor generation and chamber condensation of materials produced by x-ray ablation from NIF experiments. We obtained good agreement between modeling and Nova experiments and established the viability of lower-cost plasma-sprayed B_4C, compared to the more expensive hot-pressed manufacturing process. We defined a protection scheme for the target positioner using B_4C sacrificial layers coated onto a shock-absorbing aluminum foam. We also defined cryogenic target interfaces and analyzed effects of target emissions on generic cryogenic target support system. We reduced NIF costs through better assessment of activation issues by requiring a smaller neutron shield mass and eliminating most boron content in concrete structures and assessed the efficiency of CO_2 cleaning for first wall panels. Additionally, we established a Target Area System Code for modeling operation off the target area and assessing operational impacts of performing experiments.

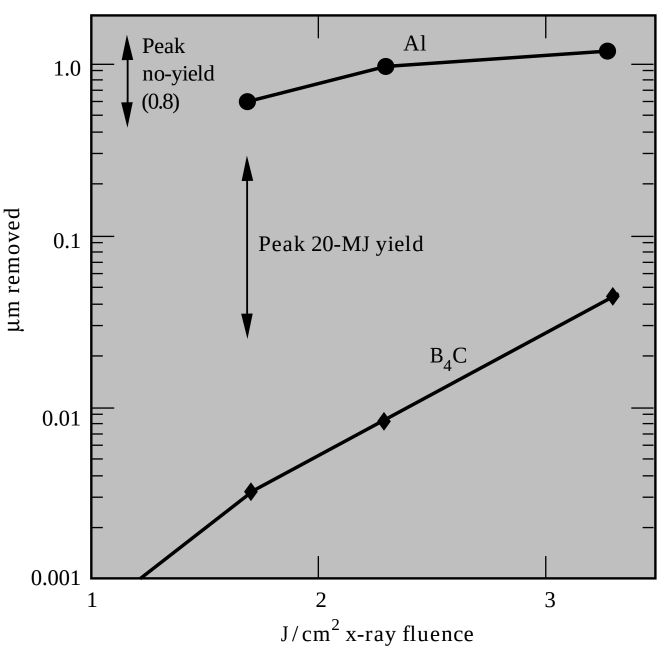

FIGURE 6. Comparison of the material removal as a function of x-ray fluence for Al and B_4C. The solid circles are data taken on Nova verifying that B_4C can be used as a first wall material to mitigate debris. (40-00-0195-0079G)

University Use of Nova

1996 was the first year of an LLNL-operated independently reviewed program for University use of Nova for broad-based SSM experiments. In response to a call for proposals, 18 proposals were received for Nova use. These proposals were reviewed by the Target Physics Program Advisory Committee, which is independent of the staff at LLNL. After review, nine proposals were approved in the fields of astrophysics, atomic physics, high-density physics, plasma physics, diagnostics development, and ICF.

An example of the synergism of ICF with the University use program is the development of the Thomson probe on Nova, which has subsequently been used to characterize hohlraum plasmas. Initial activation and experiments using the probe were done to study the structure of ion acoustic waves in a two-species plasma. An example of the decay waves showing the two ion waves is shown in Fig. 7. This is the first measurement of two-ion-acoustic waves in a two-species plasma with Thomson scattering. This work has resulted in a publication.

To promote the use of large lasers for astrophysics, the ICF Program and V Division jointly hosted a workshop on laboratory astrophysics with large lasers in February. Eighty participants from a broad-based community attended.

Laser Science and Optics Technology

The Laser Science and Technology (LS&T) Program provides laser technology development and validated performance models for NIF and advanced ICF laser systems. LS&T laser developments have spin-offs that are valuable to Stockpile Stewardship, other national programs, and U.S. industry. Many of these spin-offs, which have then been advanced by other sponsors, are now being applied to ICF needs (i.e., spin-backs). Examples include laser diodes in the NIF front-end and zigzag slab laser technology. The ICF Program is strengthened by this synergistic exchange of information between these diverse activities.

LS&T's primary activity in 1996 has been the laser and optics technology developments for NIF. A four-year focused activity for laser technology development started in 1995 and is described in the Core Science and Technology Report (authored jointly with Sandia and Los Alamos National Laboratories). The objectives of the laser developments are to provide validated design packages for the laser components and overall system design and optimization for NIF. The objective of the optics technology developments (formally

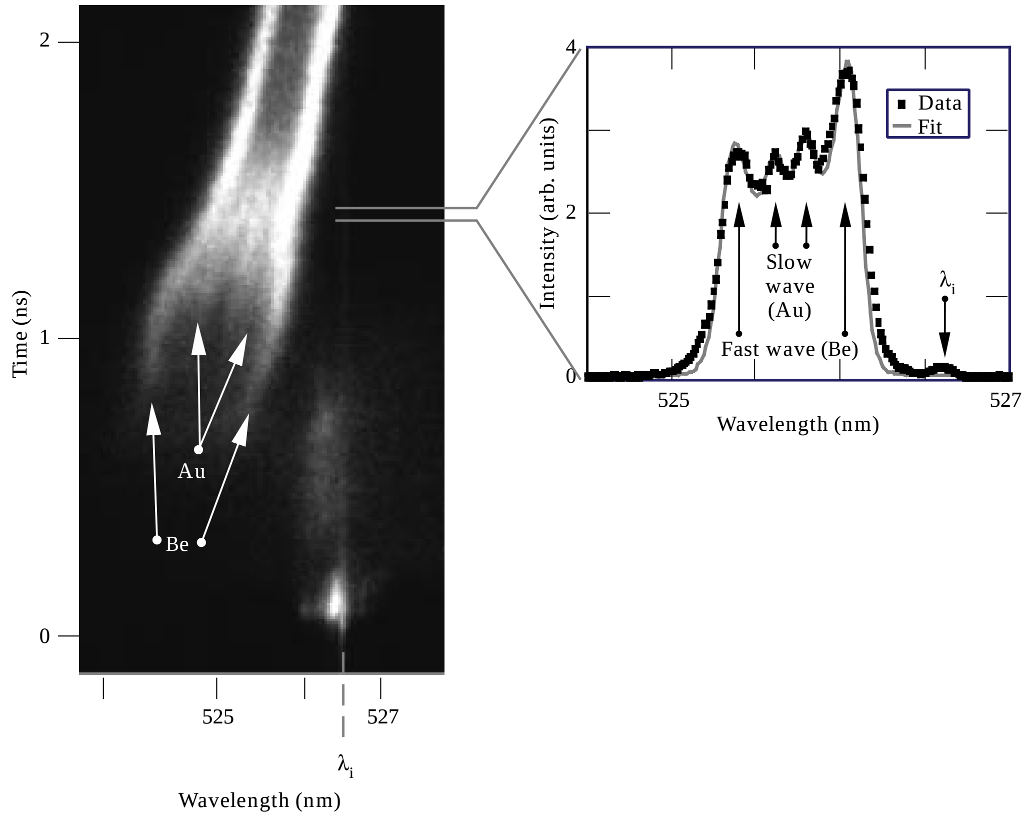

FIGURE 7. Example of results from the Nova University use program. The figure shows results from a Thomson scattering experiment that used Thomson scattering to observe the two ion-acoustic waves from a two-species plasma. This data is taken from a plasma that is 4% Au and 96% Be. (02-25-0397-0477pb01)

managed by the NIF Project) is to develop industrial production methods for the 8000 full-scale NIF optics that meet performance requirements at the required NIF cost and schedule. Both activities are described below.

Laser Science and Optics Technology Highlights

Many major Laser Science and Optics Technology milestones were completed in 1996. The amplifier module prototype laboratory (AMPLAB) was inaugurated, and the first prototype 4×2 NIF amplifier and maintenance transport vehicle were designed and fabricated. Re-optimization modeling of the NIF laser design yielded a 11-0-5 configuration of amplifier slabs in each beamline and a myriad of detailed system specifications. Beamlet was used to study the fluence and power limits and focusability of NIF, uncovering issues regarding 3ω damage and potential system failure modes. These discoveries resulted in a NIF design change, placing the frequency converter and 3ω focusing lens inside the target chamber with a 1ω window holding the vacuum. Beamlet studies on the focusability of the 3ω beam on target identified the need for amplifier cooling to increase NIF repetition rate. We have initiated an aggressive effort in this area.

The LS&T Program continued to support target physics experiments on Nova and completed the Petawatt laser beam (10^{15} W) for research on the fast ignition approach to ICF and other ultrahigh irradiance physics experiments. Diffractive optics (kinoform phase plates) were added to the Nova debris shields to provide beam smoothing for both direct- and indirect-drive studies. Hardware for 10-beam smoothing by spectral dispersion was added to Nova to support plasma physics studies.

With respect to spin-off technology, we provided key demonstrations of femtosecond laser cutting for material processing.

1996 was an important year for NIF optics development. We demonstrated the viability of continuous melting of phosphate laser glass at vendor facilities by performing quarter-scale runs at Hoya and full-scale runs at Schott using surrogate glass materials. The KDP rapid growth program matured to produce NIF-size boules (up to 43-cm size) and to yield plates which meet all the NIF 1ω optical requirements. The optics finishing companies have all demonstrated processes which meet NIF cost and performance requirements. An important development in diffractive optics capability was making a high-efficiency, high-damage-threshold color separation grating to deflect 1ω and 2ω light from the target while maintaining the focusing of 3ω light on target.

Many of our laser and optics technology developments have been done in collaboration with our French Commissariat à l'Énergie Atomique (CEA) colleagues. CEA plans to build the Laser MegaJoule (LMJ) with specifications similar to NIF by 2008 and to test a 4×2 beam bundle in a Ligne d'Integration Laser (LIL) in the year 2000, approximately. This is similar to the schedule for the first NIF beam bundle. Because of our partnership in laser and optics developments, we assisted CEA in organizing a very successful conference on solid-state lasers for ICF in Paris in October 1996, which was attended by 260 participants. This was a follow-up of a previous meeting organized by LLNL and held in Monterey, California, in May 1995.

NIF Laser Component Development

NIF laser component developments include the pulse generator, the amplifier, the pulse power system, the plasma electrode Pockels cell, the beam control system, and the Beamlet test facility. Significant progress has been made in all areas in 1996 with preliminary prototypes and tests of important physics issues.

The NIF front-end design is based on a fiber-optic oscillator, amplifiers, and pulse-shaping systems that deliver nanojoule level inputs to the 192 preamplifier modules (PAMs). During the year, the NIF design was changed from 192 to 48 PAMs. The NIF front-end system has stringent specifications on stability, pulse-shaping, and dynamic range (275). We demonstrated a fiber amplifier with a gain of 300, far exceeding the NIF specification of 36 (see Fig. 8) and converted it into a single-frequency fiber oscillator. We developed an electronic pulse-shaping system, as discussed in the 96-2 article "Temporal Pulse Shaping of Fiber-Optic Beams," that generates a computer-controlled, arbitrary waveform to satisfy NIF requirements. This fiber amplifier and pulse-shaping system are now being transferred to industry, who will manufacture the NIF units. The purpose of the regenerative amplifier (regen) is to amplify nanojoule temporal-shaped pulses up to the millijoule range with pulse-to-pulse stability of <3% rms. To maintain such high stability, the regen rod amplifier is pumped with laser diodes. Output from the regen is further amplified up to 22 J by passing four times through a flashlamp-pumped, 5-cm rod amplifier, or possibly in a 1-Hz repetition-rate zigzag amplifier. The rod amplifier system has demonstrated up to 14 J and is now being redesigned to produce higher output and less temporal pulse distortion. Energy from the four-pass amplifier is split to supply equal input energy to a "quad" of four beams, all of which will focus together on the target after further amplification through the full-aperture amplifiers.

FIGURE 8. The NIF fiber oscillator and fiber amplifier demonstrated a gain of 300, far exceeding the NIF specification of 36.
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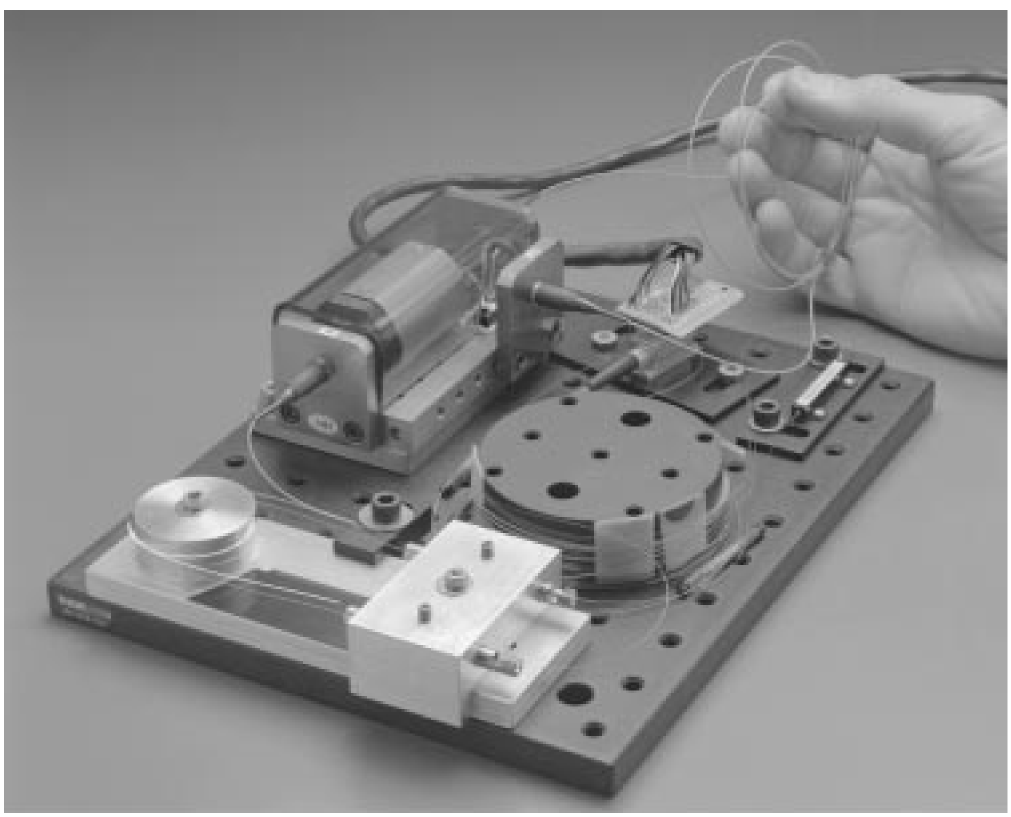


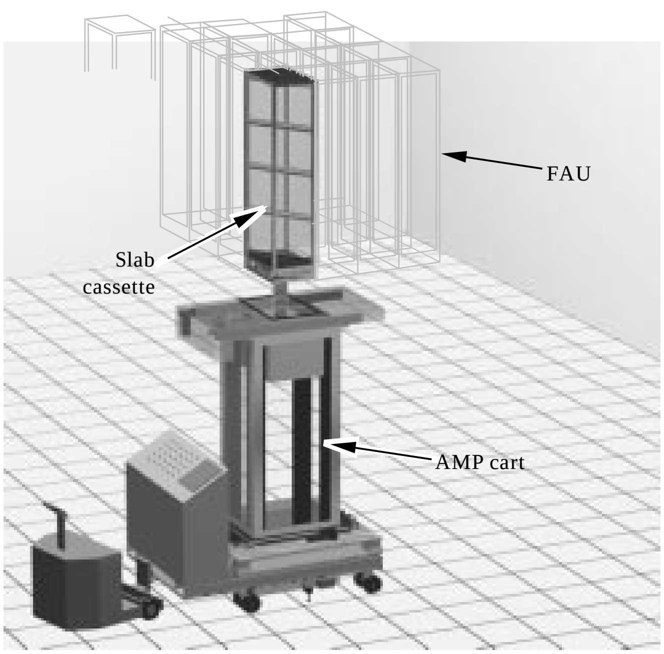
AMPLAB is the key facility for testing the full-aperture amplifiers. Testing will provide essential information on gain, wavefront performance, cooling recovery, and the degree of cleanliness in assembly and maintenance that affects the lifetime between amplifier refurbishments. AMPLAB construction began in 1996 and will culminate in full-scale amplifier testing in 1997. The 4×2 (four slabs high by two slabs wide by one slab long) amplifier module and a cart to load a cassette of amplifier slabs were designed and parts were procured (see Fig. 9). We expect to have the amplifier module and cart assembled and module tests to begin by mid-1997.

Flashlamp cooling will be implemented to increase NIF's shot rate, ideally reducing the wait between shots. The wait is for the thermal distortions of the amplifier slabs to diminish, returning the beam to an adequate quality on target. Without active cooling, adequate beam quality may not return for much more than eight hours. However, by cooling the flashlamps, the wait time can be reduced to eight hours and possibly less. Detailed modeling and tests on Beamlet have greatly increased our understanding of the relationship between amplifier slab temperature and beam wavefront and focusability as discussed later. The 4×2 prototype amplifier module in AMPLAB will have gas-cooled flashlamps to test the concept at the NIF scale.

A large-aperture diagnostic system (LADS) will make amplifier gain and wavefront measurements of the AMPLAB module. (LADS is a cooperative development with our French CEA colleagues.) This system consists of a probe laser with large-aperture telescopic beam optics, scientific-grade CCD cameras, and an interferometer.

The reliability of the 7000 NIF flashlamps is very important. The NIF lamps, at 4.3-cm bore and 1800-cm arc length, are the largest commercial lamps ever made and dissipate an unprecedented 36-kJ electrical energy per shot. We have tested prototype lamps from two U.S. makers with a set of six lamps from each company lasting over 20,000 shots. We are also testing lamps from foreign vendors.

The pulsed power system provides the energy for the flashlamps. NIF requires approximately 330 MJ of stored energy. To reduce the cost by approximately a factor of two from previous systems, this large amount of energy will be provided by relatively large, 1.7-MJ modules. NIF pulsed-power development is shared



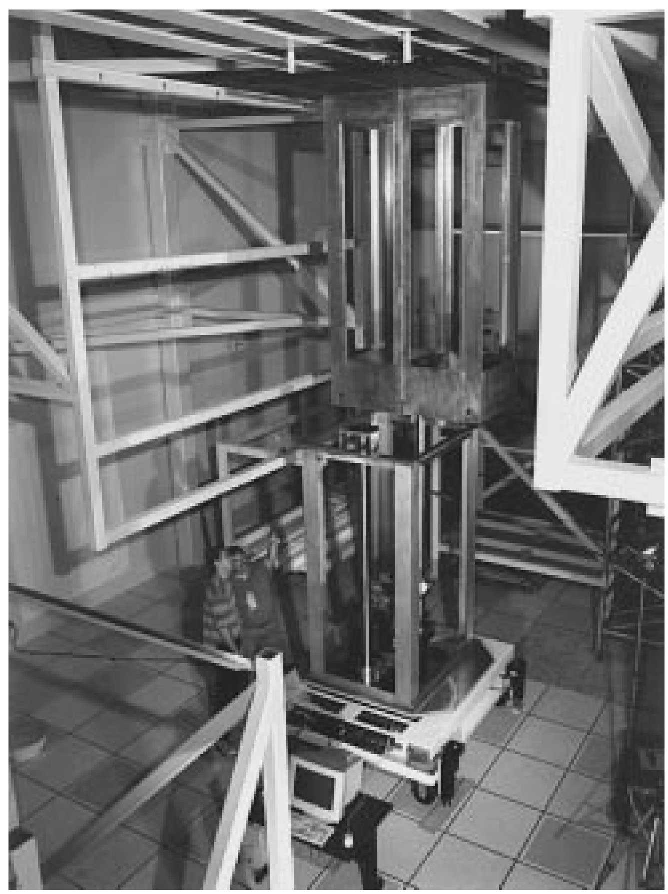


FIGURE 9. A cart inserting amplifier slabs into the 4×2 amplifier module. (70-00-0996-2187pb01)

between SNL and LLNL. LLNL is responsible for capacitors, power supplies, and other components, while SNL is responsible for the switch and integrated module testing. During 1996, we tested NIF-like capacitors from two U.S. vendors and several foreign vendors. To reduce fabrication costs, the new capacitors have a higher energy density and more capacitance per can. The NIF switch must reliably handle 500 kA. We have found one commercial switch (high-pressure spark gap) that may meet NIF requirements for at least 1000 shots between refurbishments. We are also working with Russian colleagues on the development of a solid-state silicon switch that has potential for an even longer lifetime. Fault mode testing was done with a commercial partner to verify the viability of the large energy parallel banks planned for NIF.

Significant progess has been made on the plasma electrode Pockels cell (PEPC), with the development of a densely packed prototype for use in a 4 × 2 beam bundle. The NIF design calls for four PEPCs stacked vertically in a single replaceable unit, but electrically the unit is two 2 × 1 modules. This year we designed and assembled a 2 × 1 module to test this concept (see Fig. 10). Initial tests of this prototype appear highly promising. We proved that it is possible to use a metal housing that is optimally biased at the anode potential to produce a uniform discharge and optical switching. One of the key concerns regarding the PEPC was that magnetic coupling between apertures could disrupt discharge uniformity. However, experiments with externally induced magnetic fields showed no adverse effect from having several apertures in close proximity provided the current returns are properly shielded magnetically.

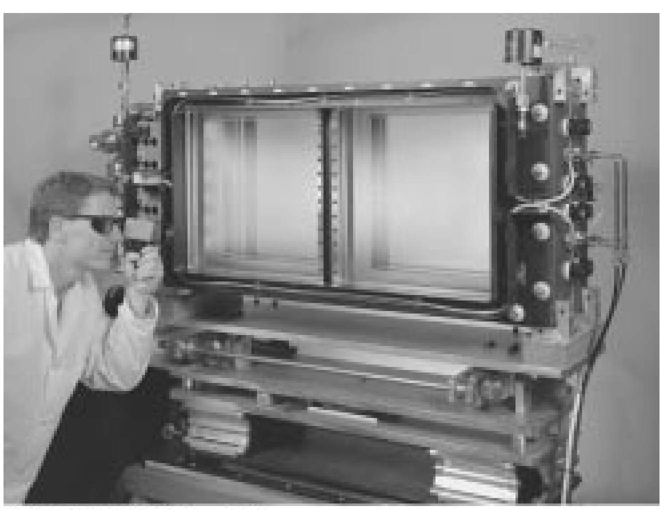


FIGURE 10. A 2 × 1 prototype of the plasma electrode Pockels cell will test the NIF design. (70-00-0297-0280pb01)

To align and control the large number of NIF beams at an affordable cost, many new concepts and simplifications of previous systems have been implemented. A 1/10 scale optical layout of a NIF beamline was built to test the alignment and control concepts. Both near-field and far-field beam sampling and beam centroiding systems have been tested. The use of a grating beam sampler at the spatial filter pinholes minimizes the required power of the alignment beam. Tests of diagnostic concepts have also been conducted at 1/10 scale, including optical damage monitoring concepts. This concept has also been evaluated on Beamlet. We have also tested a high-energy, far-field measurement system on Beamlet that could measure the performance of each NIF beam.

Development of the NIF control system has focused on the selection of the overall system architecture and supervisory software framework. We are building prototypes of a distributed timing system, auto alignment front-end processors, motor control processors, and integrated energy diagnostics.

Wavefront control is another important aspect of the NIF systems. For efficient frequency conversion and high focusability on target, the NIF beam needs a deformable mirror to correct wavefront aberrations accumulated during the multiple passes through the amplifiers. The NIF specification is for 95% of the focused energy to be contained in a 70-microradian cone (500-micron focal spot). This is consistent with a beam that is 10 times diffraction-limited at 1 micron. Beamlet uses a small 7-cm aperture deformable mirror with 39 actuators to produce the necessary precorrection before injection into the multipass system. We have developed a full-aperture (40-cm square) deformable mirror for use as one of the end mirrors in the multipass cavity. This component will minimize the beam divergence throughout the laser chain, improving alignment accuracy and increasing beam transmission through the spatial filter pinholes. Installation and testing of this prototype on Beamlet is planned for early 1997.

System Integration Tests on Beamlet

The full energy beam diagnostic system constructed for Beamlet in 1995 was used during 1996 to measure the focal energy distribution with and without a KPP. These measurements meet NIF specifications for ICF ignition targets, but confirm the importance of wavefront control for NIF beam focusability. One determinant of beam focusability is amplifier cooling. Figure 11 shows the relationship measured on Beamlet between slab temperature rise and beam divergence. To reduce thermal-driven phase aberrations, in 1996 we installed on Beamlet a “t-1” system to allow the deformable mirror to correct aberrations up to one second before the shot. We also made detailed measurements of beam modulation growth with

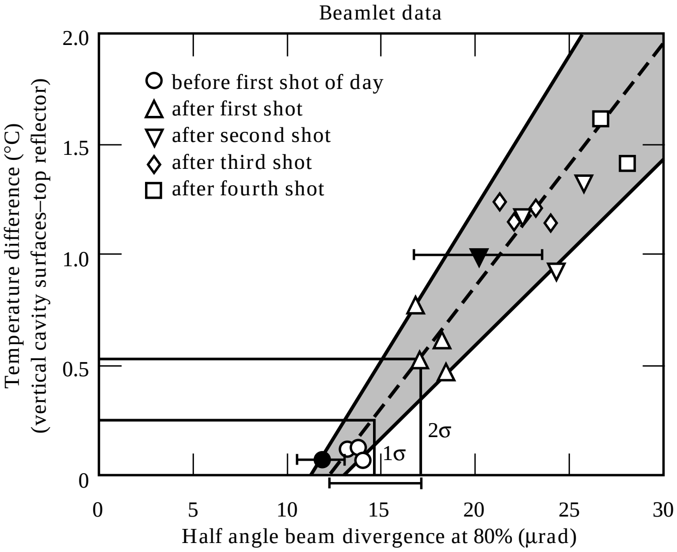


FIGURE 11. Slab temperature rise vs beam divergence, measured on Beamlet. (70-00-0197-0124pb01)

peak power as caused by nonlinear self-focusing. We investigated the effect of spatial filtering on beam modulation and the limits in filtering caused by "pinhole closure" with 20-ns duration ICF ignition pulse shapes. Optimum pinhole shapes and materials are still under investigation.

During Beamlet tests in September, we imploded, for the second time, the input lens to the transport spatial filter. Unlike the first implosion, this accident occurred because of the inadvertent absence of bandwidth on the beam which would have normally prevented transverse stimulated Brillouin scattering in the lens. Because of the implosion threat, we have reduced the stress in the NIF lens design to a level where implosion should not occur (500 psi), and we are now developing a fail-safe bandwidth system. We have also changed the design of the NIF final optics assembly to use a 1ω input window with the frequency conversion crystals and 3ω focusing lens mounted inside the vacuum. This design reduces the damage threat (1ω rather than 3ω) on the atmospheric-pressure-loaded optics. Testing the new final optics configuration on Beamlet will be a major activity in 1997 (the Beamlet "mule" campaign).

NIF Modeling and Optimization

Because of the magnitude of the NIF Project, it is imperative that the design be both cost-optimal and meet the NIF's functional requirements. Numerical modeling and optimization have played a major role this year in fulfilling both of these requirements. Over the past few years, we have developed computer codes capable of simulating the detailed evolution of the beam as it propagates through the chain elements, including effects of optical aberrations, transverse gain variation, multipass gain saturation, nonlinear self-focusing, phase correction with deformable mirrors, and frequency conversion. Separately, we have developed codes that model the propagation of flashlamp light in the pump cavity, the excitation of the laser medium by that light, depumping due to amplified spontaneous emission in the medium, and the prompt thermal loading and ensuing optical distortion in the slabs. Both of these sets of code can run in a parallel-processing mode on our 1-gigaflop cluster of 28 workstations, and can act as the computer engines for large multivariable parametric studies or constrained optimizations. This computational capability was used to examine the predicted performance, cost, and safety of over 100,000 different variations on the NIF configuration—varying such parameters as slab counts in each of the three potential amplifier locations (main, switch, and boost), optical aperture, slab thickness and doping, flashlamp packing and pulse length, pump reflector shapes, pinhole sizes, spatial filter lengths, converter crystal thicknesses, and the detuning angle. The NIF design configuration was chosen as a compromise between cost-effectiveness and performance margin. Subsequent detailed modeling has been used to establish the interface and component specifications and to assess engineering change requests to the baseline design.

NIF Optics Manufacturing Developments

We are following a four-phase program to meet the NIF optics requirements: development, facilitization, pilot production, and production. The *development* phase is used to identify appropriate manufacturing technologies, qualified companies, and to demonstrate prototype production processes by making a small number of full-size optics to NIF specifications. The *facilitization* phase is used to design, build, and install the NIF production equipment, and to modify and / or expand the production facilities as necessary to house the equipment. The *pilot production* phase is used to verify production readiness of the manufacturing facilities and processes. This work includes hiring and training the production staff, manufacturing about 10% of the NIF optics to demonstrate specifications and production rate requirements, and delivering the optics needed for the first bundle. Finally, the *production* phase is used to manufacture the balance of the optics needed to construct the NIF.

Laser materials: Phosphate Laser Glass, KDP/KD*P Crystals, and Fused Silica. We are working with two companies to develop continuous melting technology for platinum-free phosphate laser glass for the NIF—Schott Glass Technologies in Duryea, PA, and Hoya Optics in Fremont, CA. Both companies can also produce this glass using conventional batch processes.

As part of this development effort, the companies have paid considerable attention to determining the optimum composition of the glass. Schott, working closely with LLNL scientists, has developed a new composition, LG-770, for the NIF. In 1996, Schott finalized the composition of LG-770 and batch-melted ten of these slabs for testing on Beamlet. Hoya has elected to melt LHG-8 for the NIF; this is the composition used for Nova. In 1996, Hoya batch-melted nine slabs of LHG-8 at NIF size and specifications for testing in AMPLAB in 1997–8.

Schott and Hoya are taking different routes to the NIF continuous melting technology. Schott is going directly to a full-scale design, while Hoya is doing its development at subscale, and will not build a full-scale melter until the facilitization phase of the NIF Project. In 1996, Schott completed annealing and testing of a NIF-size BK-7 glass analog of laser glass melted in 1995, as shown in Fig. 12.

Forming the glass into a continuous strip is one of the most critical aspects of continuous melting. The BK-7 glass analog met the NIF homogeneity specification, and provides us with greater confidence that the Schott full-scale process will be successful. Also during 1996, Schott completed the detailed design of the full-scale melter and ordered most of the major equipment. Schott also began construction of the building that will house the melter. Installation of the full-scale melter is scheduled to be complete in mid-FY 97, and will be followed by the first full-size continuous melting campaign of phosphate laser glass.

Early in 1996, Hoya operated their subscale continuous melter and formed the phosphate laser glass at about one-fifth NIF scale. Later in the year, the melter and former were reconfigured, and Hoya executed another campaign to form glass at one-half NIF scale (see Fig. 13).

Remarkably, this glass exceeded the NIF platinum inclusion specification, met the IR and UV absorption specifications, and was within a factor of two of the homogeneity specification ($\Delta n \cong 4 \times 10^{-6}$ the specification of 2×10^{-6}). More detailed investigations of the homogeneity at fine spatial scale will be conducted in 1997 to ensure that the glass will meet the transmitted wavefront power spectral density (PSD) specification upon finishing. Hoya will refine their melter design further in 1997 in preparation for designing the full-scale melter that will be constructed in 1998.

The KDP / KD*P rapid crystal growth program produced the first NIF-size KDP boules in 1996 (see Fig. 14). These crystal boules ranged from 43 to 48 cm, and are large enough to yield the <001> "z-plates" needed for the plasma electrode Pockels cell. KDP boules of approximately 51 cm (with a goal of 55 cm) are needed to yield the Type I second harmonic generation crystals

FIGURE 12. NIF-size BK-7 glass analog of laser glass melted in 1995, annealed and tested in 1996 (by Schott). (70-30-1295-2695pb02)

(a)

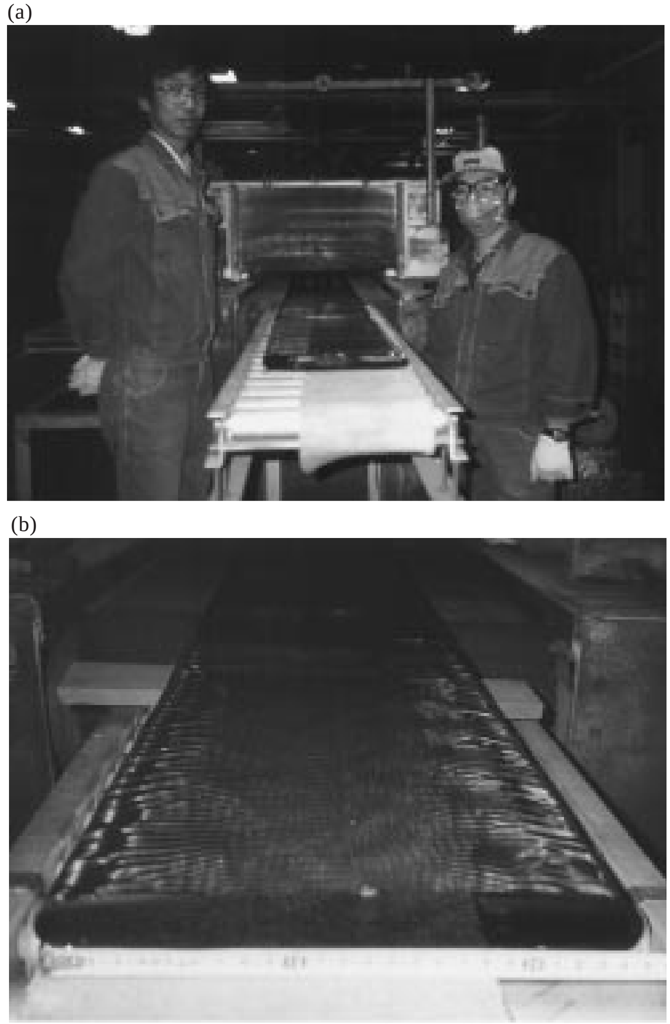


FIGURE 13. Phosphate laser glass formed by Hoya's subscale continuous melter in 1996 at one-fifth NIF scale (a) and at half NIF scale (b). (70-30-0496-0989pb01 top and bottom)

for NIF. Two crystal plates were fabricated from a representative boule and were found to meet all of the NIF optical and damage specifications for 1ω. The growth of these large boules was enabled by stiffening the platform base upon which the crystal grows. All of the growth runs that produced these boules terminated earlier than intended, with spurious crystals appearing in the solution and eventually attaching to the main boule.

The spurious crystals were determined to originate from the main boule, and are created by very slight relative motion between the crystal boule and the platform that breaks off microscopic crystal chips from the boule edges. Efforts in 1997 will be focused on reducing the stresses that produce this relative motion.

Solution inclusions tend to form on the pyramidal <101> faces of rapid growth crystals at the rotation parameters (rotation rate, acceleration, and rotation period) used to grow the large boules to date. These inclusions limit the number of usable plates which can be obtained from these boules. Until the platform was stiffened, we were limited to very low acceleration rates of 50 revolutions per minute per minute (RPM^2); exceeding this acceleration rate led to catastrophic failure by fracturing of the boule. Using a stiffer platform base enabled the use of higher acceleration rates that mitigated the severity of the solution inclusions on the pyramidal faces. An effort was initiated in mid-1996 to understand the nature of the hydrodynamic conditions in the rapid growth system, and of their correlation with morphological instabilities on the growing crystal faces. Scaling analyses relating conditions in the small tanks, where these inclusions rarely occur, and the large tanks, where they frequently occur, indicate that by further increasing the acceleration rates and periods these inclusions can be eliminated. Refinement of this understanding will continue in 1997 in conjunction with the efforts to increase the size of the KDP boules.

Continuous filtration to remove particulate impurities has long been associated with producing high-damage-threshold crystals. A full-scale continuous filtration system was built in 1996, and used successfully to grow a KDP crystal in a subscale crystallizer. The 3ω damage threshold of this crystal was 14 J/cm^2, which marginally meets the NIF requirement for operation at 1.8 MJ. The damage threshold of this crystal is about 30% lower than that of the best conventionally grown crystals. Careful studies in 1996 of damage in both rapidly grown and conventionally grown crystals have indicated the presence of defects in addition to particulates that may ultimately determine the 3ω damage threshold. A primary goal of the KDP group in 1997 is to develop suitable diagnostics for characterizing damage and identifying the critical defects that determine the damage threshold. While continuous filtration is necessary to consistently achieve high damage

FIGURE 14. Rapid crystal growth technology, which allows growth of KDP crystals at 10-20 mm/day instead of 1-2 mm/day using traditional technology, is being scaled up to produce 55 cm crystal boules needed for NIF. In FY96, we produced the first large boules of KDP which yielded 41 × 41 cm plates needed for the NIF plasma electrode Pockels cell; these crystals met all NIF specifications. FY97 efforts will focus on further scale-up to 55 cm needed for the second harmonic conversion crystal plates, and on the growth of deuterated KDP (DKDP) needed for the third harmonic conversion crystal plates. (70-50-0996-2193pb01)

threshold in KDP, it may not be sufficient by itself. Nevertheless, NIF-size crystals will be grown with continuous filtration in 1997, and evaluated for damage in parallel with the continued, more fundamental studies on KDP bulk damage. The 3ω damage threshold of the boule from which the z-plates were fabricated was 12 J/cm^2, about 10% lower than that of the subscale crystal grown with continuous filtration.

In addition to effort aimed at increasing boule size, reducing inclusions, and understanding damage in 1997, the KDP group will also begin to grow full-size KD*P (deuterated KDP) crystals by rapid growth for the third harmonic generation crystals.

Corning Inc., in Corning, NY, is working to improve its fused silica deposition process and adapt its furnace design to optimize the fused silica boule geometry for the NIF requirements. This work involves increasing the furnace size, the thickness of the boules, and the deposition rate. Significant progress was made on burner modeling and single burner experimental studies, which indicates that the Corning goals for boule thickness and deposition rate can be met. The first implementation of this new design will be tested in mid-1997.

Fused silica boules from Corning tend to have moderately large index inhomogeneities in the center of the boule; this material is generally not used for ICF optics since it fails the homogeneity specification. A careful study of representative samples of this material using phase interferometry was initiated in 1996 to investigate the possibility of using the deterministic finishing processes for lenses and windows (described below) to correct this inhomogeneity, thereby substantially increasing the yield and reducing the cost of fused silica for NIF. The magnitude and gradient of the inhomogeneity was found to be small enough that we, along with the finishing vendors, are confident that this approach will be successful. Hence, the NIF specification for fused silica was relaxed, and the projected cost reduced accordingly.

Optics Fabrication: Flats, Lenses, and Crystals. Plano optics (flats) include amplifier slabs, mirrors, polarizers, windows, diffractive optic substrates, and debris shields. Finishing technology development for all of these optics includes deterministic figuring to minimize the time and cost needed for production. Figuring traditionally contributes about half of the cost of these optics. Other development activities common to these optics are cleaning and surface inspection. Improved cladding technology is required for the amplifier slabs, and finishing processes which produce high 3ω damage threshold surfaces are needed for the diffractive optic substrates and debris shields.

We are working closely with three companies on plano optic fabrication technology—Eastman Kodak in Rochester, NY, Tinsley Laboratories in Richmond, CA, and Zygo in Middlefield, CT. Each company has taken a different route to expand their existing capabilities to meet the NIF requirements.

However, these three companies agreed in 1996 to work together with LLNL and LLE to jointly develop generic technologies outside of their traditionally competitive sphere: edge cladding for amplifier slabs, precision cleaning, and surface inspection. This collaborative effort will minimize the cost of the development program and produce superior results more quickly by capitalizing on the unique strengths of each of the partners. The formal collaboration was initiated in late 1996; the development tasks will be concluded in late 1997.

Kodak has developed small-aperture figuring technology for a variety of defense and astronomy applications. For example, ion-beam figuring was used for final figuring of the hexagonal Keck telescope mirror segments. Kodak first applied their technology using subaperture polishing tools to phosphate laser glass amplifier slabs during the Beamlet Project in 1993. Residual errors caused by overlap of the individual passes of the tool produced ripple that was unacceptable for use on Beamlet. However, by improving the tool design and figuring process, Kodak was able to meet the NIF amplifier PSD specification. This specification is extremely tight to control peak laser fluence due to nonlinear processes limits wavefront aberration in the mm to cm lengthscale of less than one hundredth of a wave. Kodak's process is essentially ripple-free, producing surfaces that meet this specification with only two figuring iterations. Traditional continuous polishing (CP) technology typically requires ten or more iterations to achieve the final figure specification.

Kodak also made substantial progress in improving its CP technology used to polish the plano optics prior to entering its small tool process. Extensive process modeling coupled with real-time diagnostics were applied to a subscale CP machine to demonstrate highly deterministic CP polishing. Kodak will modify their full-scale CP machine in 1997 to demonstrate the process on NIF-size optics.

Tinsley also uses small tool polishing technology for final optical surface figuring. Traditionally, Tinsley has focused on manufacturing high-precision aspheric lenses and other complicated optic shapes. However, Tinsley is adapting this technology to plano optics for NIF. Tinsley designed and built full-scale edging, grinding, and polishing machines in 1996 that are needed for the development program, and can also be used for NIF production.

In 1996, Tinsley used these machines and its improved figuring process to manufacture mirror blanks that met the NIF specifications; these blanks will be coated and tested on Beamlet in 1997. Tinsley, who had no previous experience with edge cladding, also began an intensive campaign to develop the capability for cladding and finishing NIF amplifier slabs. The company produced its first amplifier slab in 1996. In 1997, Tinsley is scheduled to clad and finish several of the amplifier slabs for AMPLAB.

In contrast to Kodak and Tinsley, Zygo uses its CP machines for final figuring rather than a subaperture polishing tool. To improve the determinism of this process, Zygo has substantially improved the stability (long-term flatness) of the lap surface. In 1996, Zygo demonstrated on a half-scale CP (96-inch diameter) surface form errors of less than one-tenth wave over a fifty-hour period, substantially exceeding their goal for NIF. Zygo will implement this technology on a full-scale CP machine in 1997. The conceptual design of this machine was completed in 1996.

In addition to the figuring development, Zygo has also demonstrated fixed abrasive grinding technology using electrolytic in-situ dressing (ELID) of the grinding wheel at 75% NIF size. This technology is faster than the traditional loose abrasive grinding process, and produces less subsurface damage that reduces the polishing time to remove the damage. In 1996, Zygo also developed and demonstrated at 50% NIF-size rapid and deterministic polishing technology; this step precedes their final figuring CP process. The polishing process will further reduce the time needed and cost for polishing NIF optics.

Tinsley Laboratories has supplied most of the lenses for Nova and all of the Beamlet lenses. Until 1996, these lenses were all round. Maintaining the tight figure tolerances near the edges and corners of square optics is extremely challenging. In addition, the NIF PSD specifications are difficult to achieve using small tool polishing, as discussed above for the plano optics. Tinsley was able to fabricate several square lenses in 1996 that either approached or met the NIF PSD specification. Tinsley has now defined the NIF figuring process for all the spatial filter lenses.

The 3ω damage threshold of the Tinsley lenses is not yet at the NIF specification. Work began in 1996 to develop a more detailed understanding of the determinants of 3ω damage to fused silica surfaces. We developed modified polishing processes and postpolishing processes for two-inch substrates that consistently produced damage thresholds above the NIF requirement. Nevertheless, we do not yet have a diagnostic such as subsurface damage, roughness, or contamination that correlates with damage. In 1997, we will extend the work initiated in 1996 to develop this scientific understanding of surface damage, and work closely with Tinsley to modify their current finishing process to yield high-damage thresholds on full-aperture lenses.

KDP and KD*P crystals are diamond turned rather than polished; this technology was first applied to KDP crystals for the Nova Project at Cleveland Crystals in Cleveland, OH. The flexure coupling was redesigned during the Beamlet Project to meet the Beamlet specifications. The coupling attaches the drive mechanism to the vacuum chuck that supports the crystal on the diamond turning machine used to finish the Nova crystals. This improved flexure coupling reduced the waviness in the one- to ten-millimeter regime, but did not affect the high, frequency surface roughness. The NIF surface roughness specification is two times tighter than Nova and Beamlet to meet the energy and spot size requirements. In 1996, the machine was upgraded by designing and installing a NIF-size flywheel, and the diamond turning process was modified to produce smoother travel along the slideways. The reduced turbulence from the improved flywheel and the smoother travel yielded surface roughness reduced by 2–3× on refinished Beamlet crystals. These crystals meet the NIF specification.

Cleveland Crystals also improved their blank fabrication process in 1996 to produce crystals with significantly better surface flatness. The flatness of the 37-cm Beamlet crystals ranged from 10–15 waves, making alignment very difficult. The NIF specification is 8 waves. Beamlet crystals refinished with this new process had a surface flatness of 3–7 waves. The two 41-cm crystal plates, fabricated from the rapid growth boule described above, were flat to within 3 and 5 waves, respectively.

The diamond turning machine, currently at Cleveland Crystals, produces crystals that meet the NIF specifications, but it is not appropriate to use in NIF production except as a backup machine. The machine is now almost twenty years old, and has tercite pads and steel slideways that are inappropriate for the volume of NIF production (600 crystals over a three year period). The NIF crystal size of 41 cm is also at the extreme of what this machine can handle, and tends to produce moderately high-surface gradients at the tool entry position due to nonstraightness of the slide. In 1996, Moore Tool Company was selected to design and build a new, larger diamond turning machine for NIF using hydrostatic bearings and other improvements over the machine at Cleveland Crystals. The design will be completed in 1997, and the machine built in 1998.

Optical Coatings: Mirrors and Polarizers, and Mirror Substrates. During the advanced conceptual design phase of NIF in 1995, it was suggested that lightweight mirror substrates may be needed to meet structural stability requirements for pointing. To meet this potential requirement, we initiated an effort to polish and coat half-size and full-size lightweight mirror substrates fabricated by Hextek in Tucson, AZ. These substrates were finished at Zygo and will be coated in 1997. They are scheduled to be tested on Beamlet in late 1997.

Both mirror and polarizer coatings require laser conditioning to meet the NIF damage requirement. These coatings are conditioned by exposing them first to a very low fluence, and then to increasing fluences in discrete steps until the damage threshold is approximately twice as high as would otherwise be achieved. This conditioning process is accomplished by rastering a small beam over the coating surface maintaining constant laser fluence, and then starting again at a higher fluence. The current process uses six successive increases to the laser fluence. This process was successfully demonstrated in 1996 on full-aperture turning mirrors installed in Beamlet. The number of steps needed to condition these optics determines the number of conditioning stations for NIF. Tests on small mirrors in 1996 suggest that fewer steps may be used, as few as two or three, which would allow the use of two less conditioning stations. These results will be investigated further in 1997 on full-aperture mirrors.

Also in 1996, the damage threshold of polarizer coatings was increased well above the NIF requirement by modifying the coating design at both Spectra-Physics in Mountain View, CA, and LLE. This work was performed on subscale parts; the results will be confirmed on full-scale coatings in 1997. Substantial progress was made in developing metal hafnium as the source material for the hafnium oxide layers in polarizer and mirror coatings. The hafnium is vaporized in an oxidizing atmosphere so it deposits as HfO_2 onto the substrate. Controlling the deposition rate is far easier with Hf than with HfO_2, the source material traditionally used for high-damage threshold ICF coatings. The improved rate control substantially improves the layer thickness control, thereby increasing the performance and yield. In addition, particulate concentrations are far lower on coatings made from Hf starting material, which also helps improve the damage threshold. NIF-size polarizer coatings will be made in 1997 from metal hafnium to confirm these results.

An automated damage threshold (ADT) system was implemented in 1996 at LLNL for testing coating damage. This system, based on scatter detection, substantially reduces the amount of operator interpretation needed to determine the damage threshold. In addition, much more data is taken over a larger area giving much better statistics for establishing the damage thresholds. Damage test systems installed at the coating vendors in 1996 will be upgraded with the ADT diagnostics as part of the NIF facilitization effort prior to pilot production.

National Ignition Facility

The National Ignition Facility (NIF) is a key component within the proposed facilities for DOE's science-based Stockpile Stewardship and Management Program. The extension of current program experimental capabilities embodied in the NIF is necessary for the ICF Program to satisfy its stewardship responsibilities. The physics and mission of the NIF for stewardship has been thoroughly reviewed by the JASON group and the ICFAC, both of whom strongly support the project.

All NIF Project management and staff positions have been filled to the planned levels. Major commercial contractors were chosen for the conventional facility architectural design, engineering services support, and construction management. Major contracts were placed with commercial vendors for optics facilitization to ensure an adequate optics production capability that meets the NIF cost goals. Work packages that reflect the national scope of the NIF Project were agreed to and implemented with the participating laboratories (Sandia National Laboratories, Los Alamos National Laboratory, and the Laboratory for Laser Energetics at the University of Rochester).

The technical basis of the NIF design was updated through a formal Advanced Conceptual Design (ACD) technical review process. Concurrent with the ACD activity, the documents that provide a hierarchy of the design requirements were reviewed and updated including the *Primary Criteria/Functional Requirements; the System Design Requirements*; and the laser system design / performance baseline. At the request of DOE, Defense Programs and other user requirements were included in the NIF design updates.

Key project controls were developed and implemented including: the *NIF Project Control Manual, the Configuration Management Plan*, and the DOE-approved *Quality Assurance Plan*. Change Control boards were established and are functioning. Cost account plans and authorizations for each work breakdown structure element were established. The commercial Sherpa Product Data Management system was selected and implemented to provide a project-wide centralized document, engineering drawing, and configuration control capability. A detailed Title I design schedule was developed, and regular baseline cost and schedule reviews implemented to track progress. Monthly and quarterly progress reports are prepared and distributed.

Title I design, which was postponed by late release in the Project TEC funding, was begun. An accelerated plan was developed and implemented, and is on schedule. Significant design progress has been made in all areas. The general arrangement of the Laser and Target Area Building (LTAB) was developed and is in configuration control; laser layouts were incorporated into the overall facility layout; and special equipment designs (lasers, etc.) were developed.

The NIF is a part of the Stockpile Stewardship and Management (SSM) Programmatic Environmental Impact Statement (PEIS). The SSM PEIS reaffirms the Secretary's statement at Key Decision One that LLNL is the preferred site for the NIF. In support of the PEIS, write-ups and supporting analysis have been provided to the DOE, and a *Preliminary Safety Analysis Statement* (PSAR) draft document was completed and submitted to DOE. A final site selection will occur after public review of the SSM PEIS and a formal Record of Decision by the Secretary of Energy.

Inertial Fusion Energy/New Technologies

Inertial Fusion Energy

A new thrust in Heavy Ion IFE research began with the start of construction of an experimental research facility to evaluate recirculating induction accelerators for the acceleration of space-charge-dominated ion beams. This testbed, supported by a variety of DOE funding sources including LDRD and LLNL Engineering Thrust Area initiatives, will develop precise beam control and sensing techniques for all IFE accelerator concepts. The 3-D computational code, WARP3d, was used extensively in the design of the testbed. The recirculator architecture is a leading candidate for major cost reductions in high-current, induction accelerators for IFE.

LLNL's leading candidate for a laser driver is based on a diode-pumped, solid-state laser (DPSSL), for which the gain medium (ytterbium-doped strontium fluorapatite or Yb:SFAP), developed previously at LLNL, is cooled by He gas, known as the gas-cooled slab (GCS) concept. In FY 1996, an experimental campaign to test a small subscale GCS-DPSSL was completed. Results were encouraging enough to propose a 100-J, 10-Hz GCS-DPSSL (called Mercury) for consideration of LDRD funding in FY 1997.

Nova Petawatt Capability

Since 1993, we have been developing a petawatt (10^{15} W) laser capability on a Nova beamline under LDRD support. The Petawatt laser will provide LLNL with the capability to test the fast ignitor approach to fusion and explore other ultrahigh-intensity physics topics. The Petawatt Project reached its goal in May 1996 when we demonstrated the world's first petawatt laser with an output of 500 J in a pulse length less than 0.5 ps. Figure 15 shows the inside of the 20-m-long, 3-m-diameter Petawatt vacuum compressor chamber that contains a pair of 70-cm-diameter pulse compression gratings to produce the subpicosecond output pulse from a spectrally chirped input pulse more than a thousand times longer in duration. A major component of the Petawatt Project was developing the technology necessary to make these large high-damage-threshold gratings, as well as developing an entirely new chirped-pulse master oscillator system for Nova with the mechanical hardware and optical diagnostics necessary for pulse compression. The Petawatt laser received a 1996 *Popular Science* "Best of What's New" award and enabled the developments leading to

FIGURE 15. Inside the Petawatt vacuum compressor chamber. The two pulse-compression gratings produce a subpicosecond output pulse from a spectrally chirped input pulse more than a thousand times longer in duration. (70-60-0796-1538pb01)

a 1996 *R&D 100* award in "Interference Lithography for Patterning Flat Panel Displays." The Petawatt Project has been generally acknowledged to be the Laboratory's most successful LDRD project to date.

Spin-Off Technologies

In FY 1996, we continued to exploit ICF Program expertise and technology of interest to U.S. industrial and government markets in areas such as:

- Health-care technology—Applications of our expertise/technology applied to medicine include (1) modeling laser–tissue interactions, (2) the establishment of a medical photonics laboratory for developing a host of new medical technologies, and (3) the development of user-defined laser diodes and diode-pumped, solid-state lasers for medical procedures (e.g., port-wine stain removal, tattoo removal, and laser surgery).
- Military visualization systems—Pulsed microchannel x-ray imaging technologies are now being applied to developing advanced night- and underwater-vision technologies for the Department of Defense.
- Advanced high-energy particle accelerators—Areas being developed to support advanced accelerator technology include (1) the development of a high-gradient dielectric-wall accelerator to demonstrate transport of electrons at 1 kA with a record gradient of 20 MeV/m using novel insulating materials, and (2) the development of a high-current electron-induction accelerator for LLNL's B-Division Advanced Hydro-Test Facility proposal (a National Radiographic Facility).
- Femtosecond material processing—The use of intense femtosecond laser pulses for precision material processing (cutting) of metals is under development for various government and commercial applications. Processing with ultrashort pulses is qualitatively different from using longer pulses. The energy in an ultrashort laser pulse is deposited in a thin layer at the metal surface. The energy is deposited so quickly that significant thermal conduction or hydrodynamic motion (shock waves) do not have time to occur. Instead, the absorbed energy effectively removes the thin layer of material. Very precise removal of metal has been demonstrated with no modification of adjacent material even at high repetition rates. The laser pulses remove material without significant thermal overlap or bulk heating.

Program Resources and Facilities

Resources

In FY 1996, financial resources for the LLNL ICF Program totaled $83.7M in DOE operating funds and $2.7M in DOE capital equipment allocations. Work-for-Others funding decreased slightly in FY 1996, with $30.1M coming from various sources within the DOE community, other federal sponsors, and international sources. At LLNL, the NIF Project received $21.7M in DOE operating funds and $34M in construction funds for FY 1996. The average LLNL full-time employee equivalent count over the year was 347.6 (excluding the NIF Project). Supplemental contract labor personnel were used in clerical, design, and engineering positions and as Nova operators. The ICF Program employed approximately 61.8 supplemental labor personnel in FY 1996.

Figure 16 shows the resources available to the ICF Program over the past 15 years and compares the operating funds provided by DOE in then-year-dollars vs the same funding discounted to reflect 1982 dollars. The figure illustrates that the real purchasing power for the DOE funding, as related to FY 1982, has remained fairly constant and is expected to remain so in FY 1997.

Figure 17 illustrates Work-for-Others funding, which is becoming a significant part of the total resources available to the ICF Program, but is expected to decrease slightly in FY 1997.

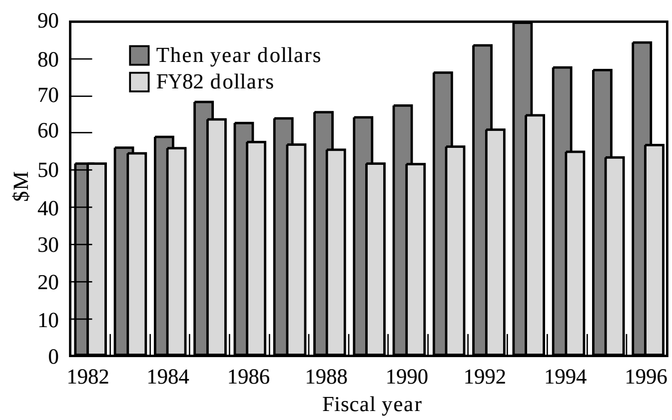


FIGURE 16. ICF program DOE operating funds. (02-20-0396-0582pb02)

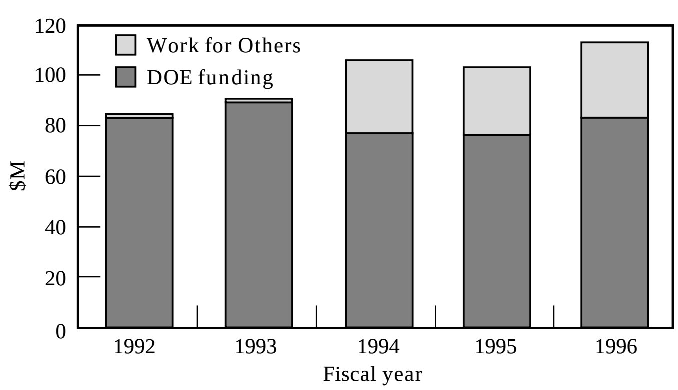


FIGURE 17. LLNL ICF program operating funding. (02-20-0396-0583pb02)

These resources enabled the ICF Program to continue its support of research and development of high-energy-density physics, laser component development, optics technology, and IFE. A couple of examples of major projects accomplished during FY 1996 are the completion of the Petawatt modification to the Nova laser system and the facilitization of the Amplifier Laboratory in Bldg. 391.

Facilities

In FY 1996, the ICF Program comprised 52 facilities—laboratories, offices, and specialized facilities totaling 636,800 gsf. Figure 18 shows the locations of ICF facilities within the Laser Programs.

The emphasis during the year was supporting NIF activities. This included accommodations for NIF housing, lab modifications, adding support facilities, and developing criteria for a major facility upgrade to the west end of Bldg. 391. Figure 19 shows a location plan for NIF lay-down space to support Laser Target Area Building / Optics Assembly Building (LTAB / OAB) construction and NIF special equipment. In addition, several maintenance projects were completed during the year.

- Detail planning was required to relocate 600 people to meet NIF staffing requirements. Additional office space was obtained during the year to support NIF Title I needs.

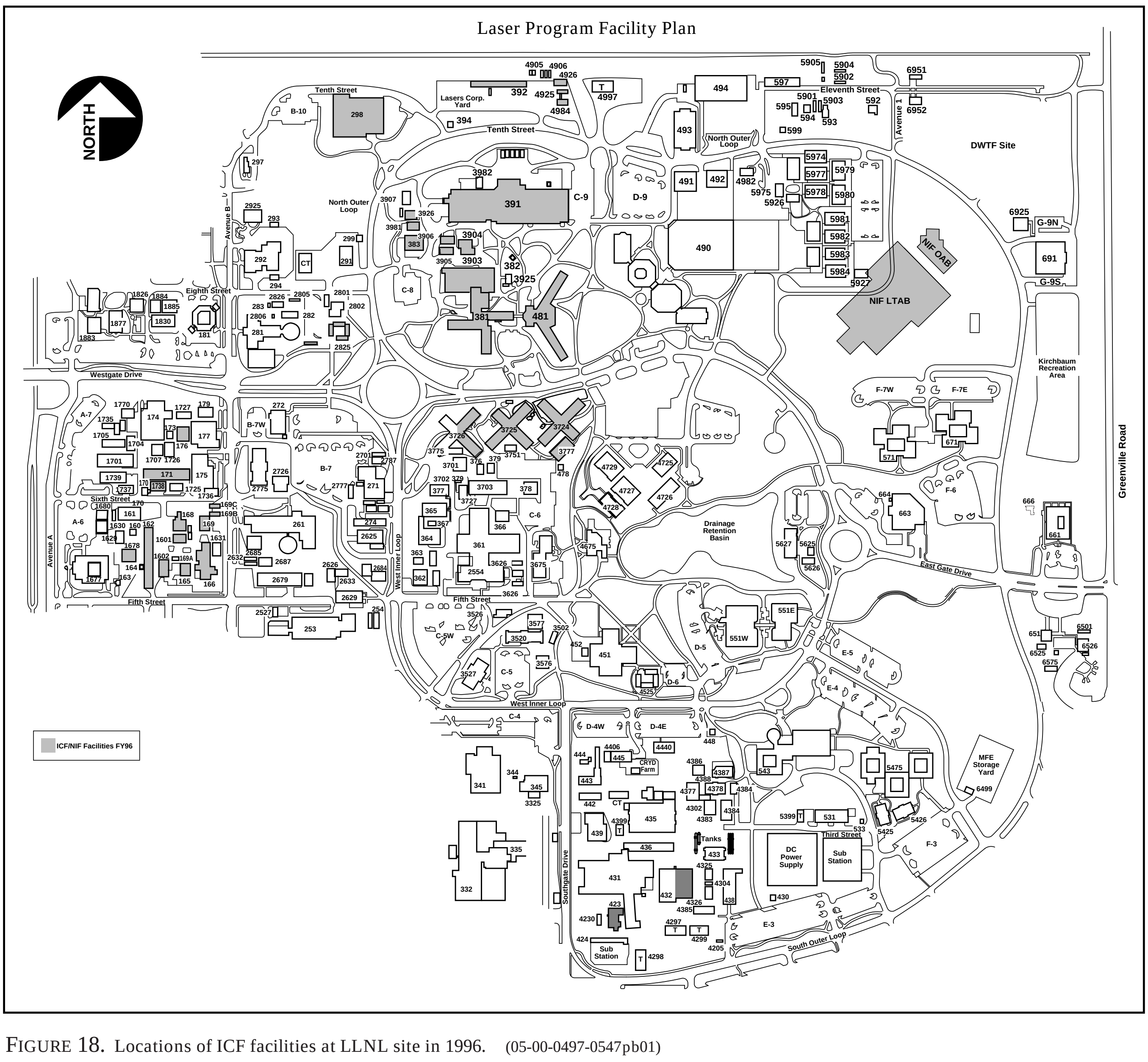


FIGURE 18. Locations of ICF facilities at LLNL site in 1996. (05-00-0497-0547pb01)

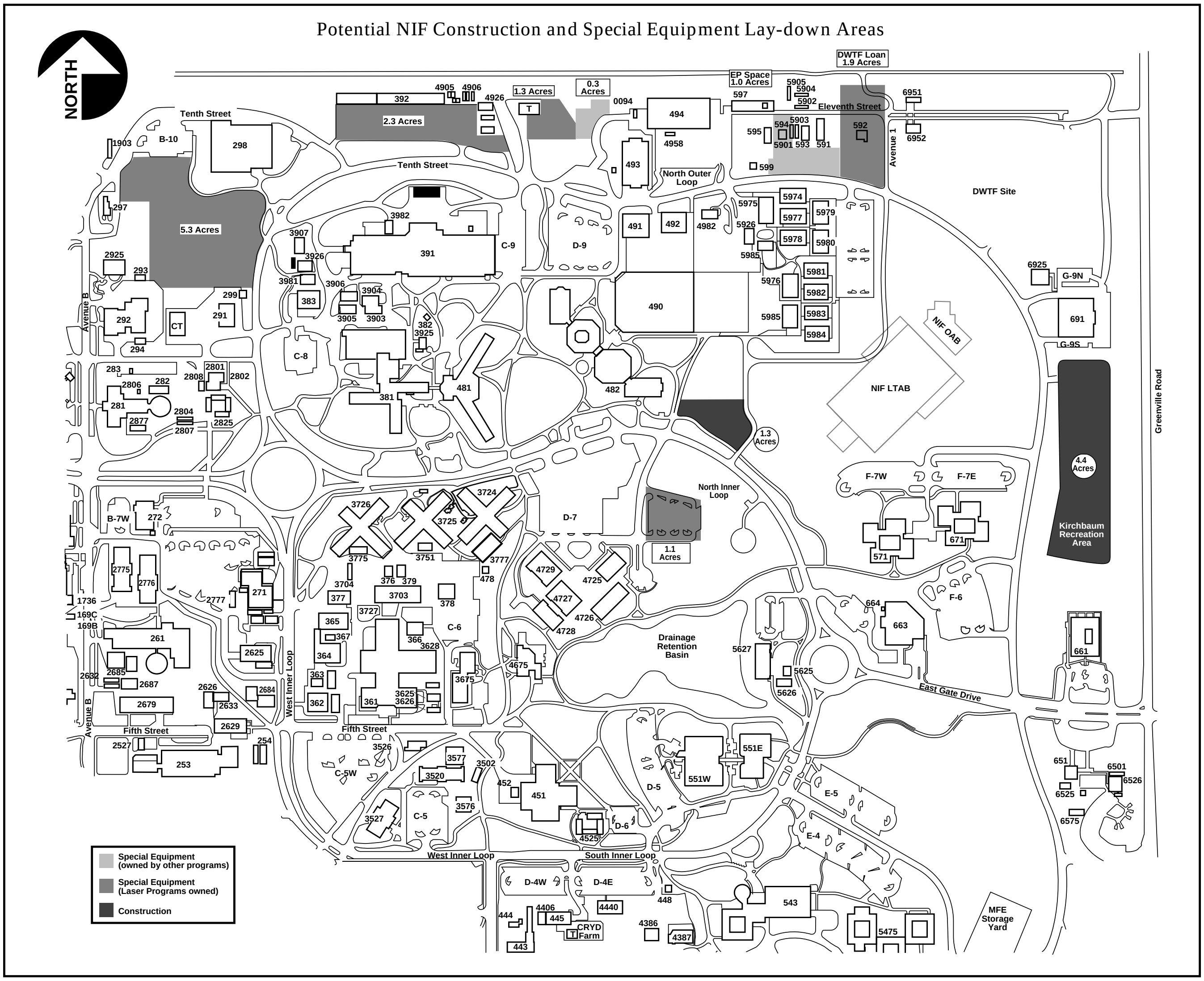


FIGURE 19. Potential NIF construction and special equipment lay-down areas. ((05-00-0497-0546pb01)

- Several major office modifications and upgrades were completed to meet NIF requirements.
- Several A Division / X Division co-location housing plans were developed through the year.
- During FY 1996, ICF facilities successfully carried out $2.3M in facility modifications and major upgrades to key laboratories and buildings.
- Completed Amplifier Development Lab and Flashlamp Test and Research Lab, plus the Control Room for monitoring and controlling both areas.
- Additional space and upgrades were started in Bldg. 432 to support NIF prototype activities.
- Completed upgrades to Bldg. 392 Optical Processing Lab and located support staff into Trailers 4924, 4925, and 4926.
- Developed Bldg. 391 west demolition and upgrades criteria to support NIF optics assembly needs.
- Completed modification to Bldg. 298 for the Laser Cutting Facility.
- Completed Phase I of Bldg. 481 power feeder upgrade.
- Several miscellaneous lab modification and alteration projects were completed during the year.

ES&H

During 1996, ICF continued its emphasis on Environment, Safety, and Health (ES&H) involvement in line operations. This included self-assessment walkthrough reviews of labs and specialized facilities throughout the Program.

Special attention was given to ES&H issues, DefTrack deficiencies, and a careful review of safety operations for Beamlet. In addition, ICF Laser / Safety Interlock Systems were given special emphasis and more manpower support for reviews and system upgrades. The following summary highlights many accomplishments:

- Completed Self-Assessment Inspection covering 273 laboratories with 289 noted deficiencies and their subsequent repairs.
- Successfully passed two formal audits by representatives of the Bay Area Air Quality Management District and one by the representatives of the Livermore Water Reclamation District.
- Corrected 119 items from the ICF DefTrack system, a laboratory-wide Deficiency Tracking System.
- Contributed to key National Ignition Facility safety documents.
- Assisted in the ICF Lock Out Tag Out implementation plan.
- Provided oversight for the Davis Applied Science student labs.
- Field-tested and proved the economic viability of recovering ethanol from the Sol Gel cleaning process, using a Solvent Recovery Still funded by EPD last year.
- Solved the ES&H issues raised during the LaNSA Pit ground water leak.
- A priority metric was developed, along with an implementation plan, to secure the approximately 188 optical tables, previously identified as potential seismic security problems.
- Relocated the Gas Mixing Lab from B343 to B298.
- Closed an administrative gap in the Incidental Fork Truck Operator's License training requirement by coordinating and documenting the hands-on training section of the course.
- Provided transportation of the ICF salvage hoppers to salvage (this service was discontinued by the transportation group).

Nova/Beamlet/NIF Updates October–December 1995

G. Hermes/R. Speck/S. Kumpan

Nova Operations

During this quarter, Nova Operations fired a total of 294 system shots, resulting in 324 experiments. These experiments were distributed among inertial confinement fusion (ICF) experiments, Defense Sciences experiments, X-Ray Laser experiments, Laser Sciences, and facility maintenance shots.

A second, 8× magnification, x-ray charge-coupled device (CCD) camera was installed and activated on the 10-beam chamber. The east and west 8× CCD cameras will replace the film based pinhole cameras currently being used to acquire x-ray images from precision pointing shots. We are currently characterizing these cameras and doing a direct comparison of the data with the existing pinhole cameras. Using the CCD cameras will greatly reduce the time required to analyze data from the pointing shots.

A complete design review is planned for the second quarter to examine the design requirements and cost of upgrading Nova to have spatial beam smoothing capabilities on all 10 beamlines. Currently, only beamlines 6 and 7 (BL–6 and –7) have the capability of smoothing by spectral dispersion (SSD). Adding SSD to all beamlines will require modification to the pre-amplifier beamline and the addition of 10 phase plates on the target chamber.

We are also reviewing the design requirements that would provide beam phasing capability to the Nova system. Beam phasing would allow us to divide each Nova beamline spatially into two halves and then to propagate two different pulse shapes through each half. At the target chamber, we would use phase plates to separate and position the beams, as required, to provide two uniform rings of illumination at each end of a hohlraum target. Each of the two rings could have a different pulse duration and shape and could be separated temporally to provide the desired laser irradiation. We are also looking into combing the capability of beam phasing with SSD.

In support of the ongoing Petawatt project, the compressor vacuum chamber was installed in the 10-beam target bay. This vacuum chamber (9 ft i.d. and 43 ft long) contains an input and output turning mirror, the diffraction gratings used for pulse re-compression, a diagnostic beam-reducing telescope, and other optics to direct the diagnostic beam outside of the chamber. An initial set of large aperture (ϕ75 cm) gratings are being fabricated for installation into the compressor, planned for the second quarter. A preliminary set of laser output diagnostics was designed and component orders have been placed. This system will also be installed and activated next quarter.

Also for the Petawatt project, a new beamline was designed for injecting the pulse from the Petawatt Master Oscillator Room into the Nova laser. The optics, mounts, and associated equipment for this beamline should be available for installation and activation during the third quarter. We are planning for a series of test shots late second quarter that demonstrate pulse compression with this system at low energy. The compressor chamber will not require vacuum for this series and the pulses will not be propagated to the target chamber.

We continued the activation and characterization of the 100 TW system. The focal spot size at the center of the 2-beam target chamber was measured to be approximately 16 μm $\times$ 22 μm using an attenuated 10 Hz (short pulse) beam. This results in about 10^{20} W/cm^2 at 40 J in 400 fs.

Beamlet Operations

During this quarter, we completed the installation, alignment, and activation of a major addition to Beamlet—a large vacuum tank equipped with optics to focus and characterize the third-harmonic beam (3ω) generated at the output of Beamlet. We also installed and activated a number of diagnostics associated with this system that will measure the properties of the beam at the plane of an inertial confinement fusion (ICF) target. We plan to use these systems to evaluate the effectiveness of focal-spot beam-smoothing schemes proposed for the National Ignition Facility (NIF), including phase plates and smoothing by spectral dispersion (SSD). The system will also provide the opportunity to test the focusing optics to be used on the NIF at operating fluences. In initial experiments done during this quarter, we measured the prime focus of the 3ω beam both with and without a phase plate. The diagnostics ready for these initial experiments included:

- Energy diagnostics consisting of a whole-beam calorimeter that measures the sum of all wavelengths, and a set of small calorimeters and diodes that measures individually the 1ω, 2ω, and 3ω energy and power.
- 1ω pointing and centering diagnostics to establish and maintain beam alignment to the focusing optics.
- Medium and narrow field-of-view imaging diagnostics to record the focal spot.
- A temporary imaging diagnostic to record the 3ω near-field beam.

At the end of the quarter, we performed several shots at 200-ps pulse duration to extend our study of 1ω near-field beam modulation at the Beamlet output. By analyzing these shots, we can determine the power threshold for severe beam breakup and filamentation that could damage Beamlet optics and can aid in determining the performance limits of the NIF laser design. In this series, we propagated a short (200 ps FWHM) high-power pulse from the cavity amplifier through the unpumped booster amplifier to simulate the conditions at the end of a long, highly saturating pulse and examined the near-field output beam carefully for evidence of breakup and filamention. We obtained higher resolution images, using an improved near-field imaging system. The system consists of a CCD camera with 1024 × 1024 pixels to record a 25 cm square portion of the beam and optics with a wider angular acceptance. In the December series of shots, we obtained data from several image planes between the frequency converters and 11.5 m beyond the converter location. These data will be helpful in determining the optimum location of the frequency converters, and the length of the NIF transport spatial filter. An analysis of the data is being performed.

We finished the design and initiated procurements for diagnostics to do central dark-field imaging of the 1ω focal spot at the Beamlet output. The purpose of these measurements is to determine the distribution of scattered light at small off-axis angles. We plan to install and activate this diagnostic during the second quarter.

NIF Design

This quarter, the Department of Energy (DOE) authorized funding to begin the Advanced Conceptual Design (ACD) for the NIF Project. Due to the delays in the FY 1996 congressional budget process, the Title I Design work was postponed until late December, at which time the full $61M for the fiscal year was received.

The ACD prepares the Project for the engineering design activity to be conducted during Title I. By the end of the quarter, the Project organization was in place and the NIF staff exceeded 75 people. Major contractors were chosen for the building architectural design and for engineering support. The Ralph M. Parsons Company was chosen for design of the Laser and Target Area Building (LTAB) and A.C. Martin for the design of the Optics Assembly Building. Master Task Agreements for engineering support were placed with TRW, SAIC, Westinghouse, and Physics International. Engineering tasks were assigned to the participating ICF laboratories (Los Alamos National Laboratory; Sandia National Laboratories, Albuquerque; and the Laboratory for Laser Energetics at the University of Rochester.

The ACD engineering activity centered around several major tasks, all leading to the general arrangement of the special equipment and the overall size of the LTAB. These tasks include: the design impact of incorporating capability for direct-drive physics experiments, determination of the need for beam expansion at the end of the laser, the length of the spatial filters, and the accommodation of requirements for the radiation effects users. Another important activity was the preparation of requirements and design concepts for assembly and maintenance of the laser system optical components and for the Optics Assembly Building. A review will be held in February to discuss the design work conducted during the ACD. Concurrent with ACD activity the NIF Project's *Primary Criteria and Functional Requirements* top-level document, which provides a hierarchy of all design requirements, was reviewed and revised. During the second quarter, the DOE will review proposed changes to this document.

NOVA/BEAMLET/NIF UPDATES JANUARY–MARCH 1996

G. Hermes/R. Speck/A. Clobes

Nova Operations

During this quarter, Nova Operations fired a total of 309 system shots resulting in 319 experiments. These experiments were distributed among inertial confinement fusion (ICF) experiments, Defense Sciences experiments, X-Ray Laser experiments, Laser Sciences, and facility maintenance shots.

As planned, we held a design review to discuss upgrading Nova to include spatial beam smoothing capability on all 10 beamlines. In support of this upgrade, a prototype phase plate and debris shield holder was fabricated, installed, and tested on the 10-beam target chamber. A prototype of the kinoform phase plate (KPP) was also fabricated and used on several target experiments. The KPP produces a smoother focus spot on target than the present phase plate and is planned to be used on the National Ignition Facility (NIF). Design modifications to the optical system for the preamplifier beamline modifications were completed, and the orders were placed. The substrates and finishing required for the KPPs were also ordered. Experiments using beam smoothing on all 10 beamlines are planned for the fourth quarter.

In support of the ongoing Petawatt project, we achieved the following tasks:

- Completed the vacuum compressor chamber and vacuum leak tested the system.
- Installed and aligned primary optical components required to demonstrate pulse compression (mirrors, gratings, and diagnostic telescope).
- Activated the basic diagnostics required to measure pulse width and bandwidth.
- Installed and aligned the new injection beamline from the Petawatt Master Oscillator Room to the Nova laser.
- Took several shots at low energy and with the compressor at atmospheric pressure to check the initial system performance.
- Obtained a low-energy compressed pulse of ~650 ps.
- Scheduled full-power shots to demonstrate Petawatt performance to be done during the third quarter .

We also developed a design for a small target chamber to be installed between the compressor and 10-beam target chamber to allow using the Petawatt beam for simple target experiments that do not require the full diagnostic capability of the 10-beam chamber. This configuration would provide more flexibility and would allow the Nova system to support Petawatt target shots without impacting the 10-beam target chamber. A final design review for the mini-chamber is scheduled for the third quarter.

Several modifications were made to the 100-TW system to improve system reliability and performance:

- Reviewed the design and purchased the hardware for a closed loop alignment system to improve system shot-to-shot stability and repeatability. Installation is planned for the third quarter.
- Installed a graphical user interface to the control system to allow the operators to configure the system more efficiently.
- Relocated the power conditioning hardware outside the oscillator room, due to excessive electrical noise problems.
- Ordered several spare parts to reduce system downtime during maintenance and repair.

To reduce film handling, processing, and digitizing, we use charge-coupled-device (CCD) cameras. We modified one of the six-inch-manipulator (SIM) based diagnostics used on the 10-beam target chamber to replace its film back with a CCD camera. We plan to modify an additional SIM diagnostic with a CCD camera by the end of FY 1996.

Beamlet

During the quarter, experiments continued on Beamlet to validate the laser physics foundations for the NIF design and addressed the following issues:

- Controlling the growth of near-field amplitude modulation in the 1.06-µm laser amplifier.
- Determining the source terms for scattered light, and its nonlinear amplification at high power in the 1.06-µm laser.
- Performing large-area damage tests and online damage conditioning of KDP.
- Performing online conditioning tests of high-fluence 1ω reflective coatings.

All of these experiments are part of long-term continuing campaigns that will include two or more experimental series.

The shots to study near-field beam modulation were in support of a working group studying the power and energy limits imposed on the output of the 1.06-µm laser by the nonlinear growth of optical noise that originates from imperfections in the beam optics. In this series, we studied the increase in near-field modulation at several planes beyond the booster amplifier output as the B-integral increased and as a function of pinhole size in the cavity and transport spatial filters. With 200-ps pulses, we used pinholes as small as 130 µrad in the cavity spatial filter and 100 µrad in the transport filter. As expected, and in contradiction to the observation made on Nova, the smaller pinholes produced smoother beams. We produced pulses with B-integrals up to, and exceeding, the NIF requirement with well controlled modulation and no evidence of filamentation. We have not yet tested small pinholes with long, high-energy pulses required for NIF; this will be an issue in future experiments.

We activated a new dark-field imaging output diagnostic to provide sensitive measurements of small-angle scattered light at the Beamlet 1ω output. This diagnostic improves our ability to accurately measure optical noise within the band between 33 and 800 µrad half angle and will allow us to quantify noise amplification that results from nonlinear phase retardation effects. We fired low- and high-power shots with various cavity pinhole sizes and dark field image blocks in the initial series to measure the noise power.

In support of the NIF materials development group, we performed large-area damage tests on KDP samples. The tests determined an unconditioned damage threshold of 8 J/cm^2 and demonstrated that large area online conditioning of KDP in a vacuum environment is effective.

We installed a set of four high-damage-threshold 1ω mirrors between the output transport spatial filter and the frequency converter, simulating the NIF transport mirror system, to investigate the feasibility of online conditioning. The alternative offline raster scan conditioning is time consuming and costly; if online conditioning can be demonstrated, it provides a more cost-effective and efficient substitute. Two of the four mirrors were offline conditioned and the other two were to be online conditioned. Anomalously high amplitude modulation (3 to 1, peak/average) at the output of Beamlet occurred on two shots early in this series. In each case, both of the unconditioned mirrors were damaged and the tests had to be terminated. The offline conditioned mirrors were more robust—only one damaged on one of the shots. We will renew our attempt to demonstrate online conditioning later in the year when additional mirrors become available.

We also removed two cavity amplifier slabs and replaced them with recently refinished slabs. During the disassembly, we noticed some degradation of amplifier components and are investigating the cause. The slabs removed had been finished using unoptimized small-tool polishing techniques. We will use high-resolution interferometry to characterize these slabs to determine if refinishing is necessary, and the laser modeling group will use the data in propagation modeling.

National Ignition Facility

During the quarter, we began Title I design, which was initially affected by delays in the Project FY 1996 total estimated cost funding. To support Title I design efforts, we updated the technical basis of the design, increased Project staff to the planned levels, developed key Project controls and documentation, and developed support infrastructure required to support the design support. The NIF Project activities are now proceeding as planned.

The technical basis of the design was updated through a formal technical review process that included the following:

- Completing an Advanced Conceptual Design (ACD) review in February, including technical and financial impacts of user requirements.
- Updating the Primary Criteria/Functional Requirements.
- Updating and improving the System Design Requirements.
- Developing optics assembly capability requirements.
- Updating the laser system design/performance baseline.

Key Project controls and reporting procedures were put in place, including the following:

- Implementing the *NIF Project Control Manual*, the *Configuration Management Plan*, and the DOE-approved *Quality Assurance Program Plan*, and providing training on key procedures and configuration management.
- Installing the commercial NIF Sherpa Product Data Management system that provides a project-wide centralized document engineering drawing, and configuration-control capability.

- Establishing cost account plans and authorizations for each work breakdown structure element.
- Developing a detailed Title I design schedule.
- Establishing regular Title I baseline costs and schedule reviews to track progress.
- Preparing and distributing monthly and quarterly progress reports.

To reflect the national scope of the NIF Project, the NIF participating Laboratories agreed to, and implemented, the following expanded workscopes:

- Sandia National Laboratories (SNL) expanded the workscope includes conventional facilities management, construction management, mechanical systems integration, target area structure analysis, the target experimental data acquisition system, and diagnostic system integration. The SNL team includes engineering design staff at Sandia—Livermore, California.
- The expanded Los Alamos National Laboratory workscope includes structural support for key opto-mechanical assemblies (cavity mirror, Pockels cell polarizer, and extra-cavity turning mirror) and target area robotics.
- The Laboratory for Laser Energetics at the University of Rochester expanded workscope includes large-aperture polarizer coatings and exploration of production capabilities for high-performance, large-aperture optics coatings.

All major contracts for the Title I design have been decided including the architecture / engineering contract for the Laser and Target Area Building (LTAB), contracted to Parsons; the Optics Assembly Building (OAB), contracted to A. C. Martin; the Construction Manager, contracted to Sverdrup; Engineering Design Services contracted to Northrup / Grumman, TRW, Physics International, and SAIC; and Management Services, contracted to XEC and LRL.

The laser system design was updated through an optimization analysis performed by a NIF Project and ICF Core Science and Technology team. This update resulted in a NIF laser configuration that is improved from the Conceptual Design Review (CDR) version. The design (the 11-0-7 configuration) has an 11-slab main amplifier, no switch amplifier, and a 7-slab boost amplifier that meets the NIF 1.8-MJ and 500-TW on-target technical requirements. This design is comparable in cost to the CDR design within the available resolution, and it meets the NIF functional requirements at lower risk. Design improvements include:

- A lower filamentation risk due to lower B-integral (1.8 vs 2.1).
- Greater similarity to the Beamlet 11-0-5 configuration, thereby reducing development costs and risks.
- Elimination of switch amplifier magnetic field interactions with the adjacent plasma electrode Pockels cell.
- Fewer laser support structures, and a shorter LTAB length.

Significant design progress has been made in all areas. Following extensive functionality and cost analysis of various building layouts and configurations, Title I design of the LTAB building began. A general arrangement of the facility was developed and is now in configuration control, and laser layouts have been incorporated into the overall facility layout (Fig. 1). Locating the LTAB and OAB at the preferred Livermore site has also been completed, which minimizes site development costs.

(a) LTAB ground level view

(b) LTAB composite view

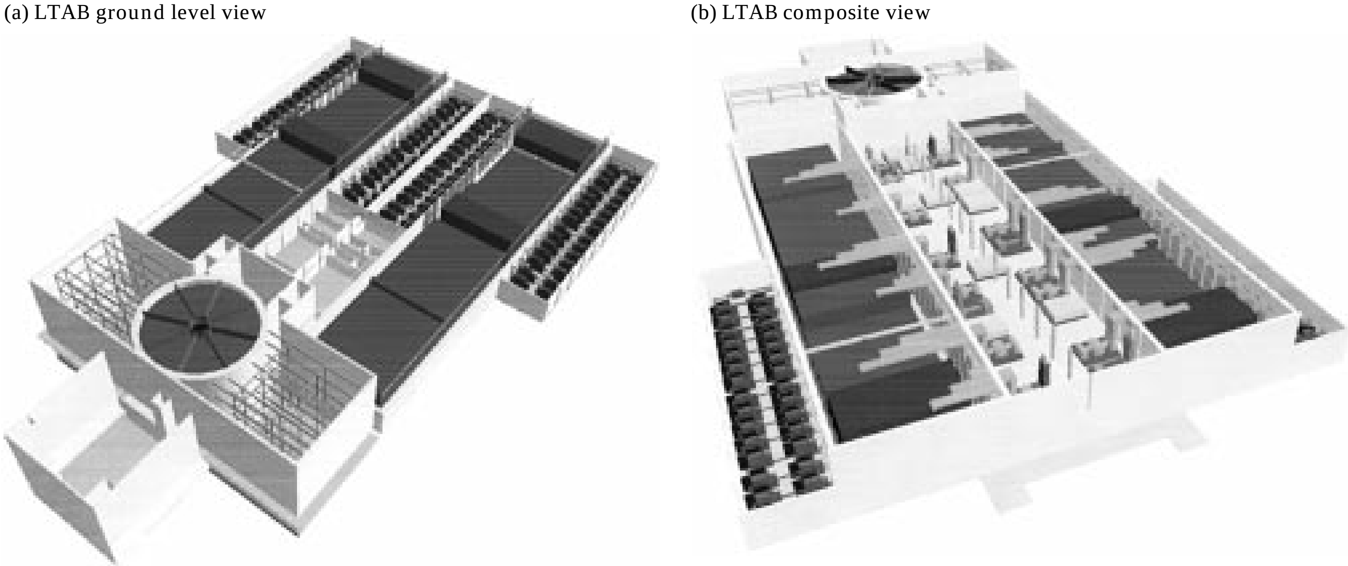


FIGURE 1. 3-D CAD models for the NIF Laser and Target Area Building (LTAB). (40-00-0496-0847pb01)

In the laser area, we completed the design analysis to determine pumping uniformity of the end slabs in the amplifier. The analysis shows that the required uniformity is met without the addition of end lamps. Design iterations, based on finite-element analysis on all the laser bay support structures, have been completed. These structures were re-engineered from the CDR to minimize construction costs and to improve their performance in terms of increasing the first resonant frequency a significant 20%. Designs for bottom loading line replaceable units (such as amplifier cassettes) into the beamline have been developed.

We completed the beamline optical component layouts within the LTAB. The design includes first-order raytrace to establish the approximate spacing between the optical components followed by the Code V layouts that provide detailed locations of the optical components. The optical sizes of the main laser components have been determined and clear aperture analysis is under way.

The NIF is a part of the Stockpile Stewardship and Management (SSM) Programmatic Environmental Inpact Statement (PEIS). The SSM PEIS reaffirms the Secretary of Energy's statement during Key Decision One that LLNL is the preferred site for the NIF. In support of the PEIS, writeups, supporting analysis, and reviews have been provided to the DOE, as well as a Preliminary Safety Analysis statement draft document. A final site selection will occur after public review of the SSM PEIS and a formal Record of Decision by the Secretary in September 1996.

During the third quarter, the mid-Title I design review will be conducted, and we will continue toward completion of the conventional facilities Title I design in September and special equipment design in October, as scheduled.

Nova/Beamlet/NIF Updates April–June 1996

G. Hermes/R. Speck/A. Clobes

Nova Operations

During this quarter, Nova Operations fired a total of 274 system shots resulting in 288 experiments. These experiments were distributed among ICF experiments, Defense Sciences experiments, X-Ray Laser experiments, Laser Sciences, and facility maintenance shots.

As a result of gradual budget reductions over the past several years, the number of Nova Operations staff has been slowly reduced to the point that a standard double-shift operation is no longer able to be supported. In an attempt to improve facility performance, the Nova Operations group formed a team to evaluate the use of an alternate work schedule for system operations. The previous schedule consisted of two standard eight-hour shifts overlapping by one hour, five days per week. The team reviewed a variety of work schedules to determine which schedule would best meet criteria provided by the Program. As a result of their study, the team recommended four ten-hour days per week of two shifts overlapping by three hours. This alternate schedule provides slightly more time for experiments, while leaving adequate maintenance time and without requiring the use of regularly scheduled overtime. As of June 10, the operations personnel have been working this new shift. Preliminary evaluation of this work schedule indicates that the system shot rate is very near that of the standard two-shift operation and that system maintenance has improved.

A final design review was presented by Los Alamos National Laboratory for phase 2 of the Full Aperture Backscatter Station (FABS II). This diagnostic incorporates a reflecting telescope to produce a high-resolution image of the target plane. Subsequent to the review, LANL determined that the primary turning mirror produced a second surface reflection that resulted in unacceptable interference with the signal from the first surface. An alternate mirror will be coated with a wide-band, high-reflective coating on the first surface to eliminate this issue. The installation schedule for FABS II will be reevaluated after the coating of this mirror.

The Gated X-Ray Imager #5 (GXI 5), modified last quarter to use a charge-coupled-device (CCD) camera readout, is still undergoing development. During initial activation, several problems were noted and repaired. We are continuing to use this camera as opportunities arise to complete testing and work out any additional issues. The use of a CCD camera allows immediate viewing of data following a system shot.

In ongoing support of the Petawatt Project, we completed the following:

- Installation and activation of the compressor vacuum system.
- Installation and alignment of a subaperture beam-diagnostic station to support the May shot series.
- Demonstration of subaperture pulse compression in a vacuum by achieving 1.25 PW during the May shots.
- Continued system installation and activation in preparation for the full-aperture Petawatt demonstration.

We are developing a plan to install a minichamber between the Petawatt compressor and the ten-beam target chamber. This minichamber will be used during the initial Petawatt demonstration to measure system performance and beam spot at focus. The detailed engineering continues for the parabolic mirror mount, target alignment viewer, and miscellaneous diagnostic hardware required to support target experiments with the Petawatt system.

We are removing the one-beam chamber located in the west end of the two-beam area to provide a lab area for the testing of the NIF final optics assembly. Other assembly processes and hardware stored in this area are also being relocated.

Beamlet

Beamlet continues to provide the testbed to validate the laser physics foundations of the National Ignition Facility (NIF) and to check laser engineering concepts and components proposed for the NIF. During the quarter, activities on Beamlet included the following:

- We quantified the limits on power output of the NIF 1.06-μm laser design that are safe from beam filamentation in the system's 1ω optics.
- We obtained far-field images in the new dark-field-imaging diagnostic that quantified the fraction of the 1ω power scattered at small angle as a function of laser output power.
- We installed reworked 37-cm aperture frequency-conversion crystals.
- We upgraded the 3ω focal-plane diagnostic system.
- We began a series of shots to characterize the 3ω focal spot and assess the damage threat to the final optics components.
- We activated an improved control system for the deformable mirror that will allow correction for gas turbulence.

The shots to study beam filamentation propagated 200-ps-duration pulses through the unpumped booster amplifier to simulate the conditions at the end of long, high-energy, saturating pulses. The short pulses provided a "snapshot" of the most stressful part of the saturating pulse and greatly reduced the irradiance averaging that takes place when a near-field image of the entire pulse is taken. The most important diagnostic in this series was a high-magnification near-field camera recorded by a 1024 × 1024-pixel CCD camera. The results confirmed that the NIF can operate safe from filamentation with delta-B values of up to 1.8 and can have adequate margin for beam-to-beam and shot-to-shot fluctuations in output. Smaller pinholes (130 μrad in the cavity spatial filter and 100 μrad in the transport filter) provide added margin over the standard 200-μrad pinholes and are preferable.

Dark-field image data of the 1ω output were also gathered from 200-ps pulses and an unpumped booster amplifier. Much of the data came from the same shots as the 1ω near-field modulation data. The diagnostic system measured the fraction of the power scattered outside far-field beam blocks of ±33, ±66, and ±100 μrad. The data provides a measurement of (1) power scattered from imperfections and finishing errors on the optics at low laser output power and (2) the growth in this scattered power with increasing laser power. This information is useful in determining noise source values for use in laser propagation modeling.

Beginning in mid-May, we installed refinished 37-cm-aperture frequency-conversion crystals on Beamlet following their characterization on the high-resolution phase matching interferometer. At this time we also aligned and calibrated the Phase II diagnostics for the 3ω focal-plane diagnostics system. New diagnostics include a very-high-resolution near-field camera that records on photographic film, a medium-resolution near-field camera that records on a CCD array, a wide-field-of-view calorimeter, a 3ω streak camera, a multiple-plane 3ω far-field camera, and a number of new and upgraded energy sensors.

Experiments to investigate 3ω beam quality and focusability began in early June following the calibration of the new diagnostics and the angle tuning of the conversion crystals. We fired a total of 19 shots in this campaign; 14 to measure the 3ω beam quality and focal spot and 5 to characterize the focal spot obtained with a kinoform phase plate (KPP). Ten of the 14 shots without the KPP were with 200-ps-duration pulses and with the booster amplifiers unpumped to achieve delta-Bs of up to 1.8 rad at power levels up to 2 TW. We investigated both small pinholes (130-μrad cavity / 100-μrad booster) and large pinholes (200-μrad / 200-μrad). The focal spot data at 2.8 TW power with and without a KPP yielded 80% power half angles of 33 μrad and 20 μrad respectively and 95% power half angles of 53 μrad and 32 μrad. Preliminary analysis indicates that the spot size is strongly influenced by thermal effects in the amplifiers, as well as by output power.

At the end of June, we completed the activation of the T_0-1 second wavefront correction system. This system allows the deformable mirror to run in closed loop up to one second before shot time and thus provides the capability for wavefront correction up to the last second before shot time. On a limited number of shots during its activation, the system corrected wavefront error caused by turbulence on shots taken early in the day but was increasingly unable to make the correction as the heat accumulation in the amplifiers and the corresponding turbulence increased after repeated shots, indicating that turbulence cell sizes become smaller than the deformable mirror could correct due to its finite actuator separation.

National Ignition Facility

We made significant progress in Title I design this quarter; based on current accomplishments, the Project is expected to meet all FY 1996 critical-path milestones and complete the design as planned in September (Laser and Target Area Building conventional facility) and October (special equipment and Optical Assembly Building). The Mid-Title I Design Review, completed at the end of May, served as an interim checkpoint in the design process. The status of the Mid-Title I design was presented to a review committee consisting of individuals from all the participating Laboratories as well as outside reviewers. The recommendations and comments were documented and assembled into a package and distributed to Project personnel for use in updating the design.

While the three-month total estimated cost (TEC) funding delay slowed NIF staffing and delayed the start of design, a catch-up plan was developed and implemented and is working well. This catch-up is based on a well integrated NIF / ICF team, augmented by effective use of Master Task Agreements (MTAs) with commercial companies, coupled with rapid narrowing of design options.

Engineering documentation and infrastructure are developed to the degree necessary for the current design effort. The Computer Aided Design and Drafting (CADD) systems are fully operational, the Product Data Management (Sherpa) hardware and software are implemented, and the required subsystem design requirements and interface control documents are in place.

In addition and in parallel with the intensive design effort, Title I cost and schedule estimates are being developed in all areas. The system and database are operational, with inputs generated by the responsible engineers and the system and rates controlled by the NIF Project Office. Initial inputs are essentially complete, and verification is under way.

Specific progress in the various areas is outlined below.

- The contract for construction management services was awarded to Sverdrup, and personnel were onboard for the Mid-Title I Design Review. Fast tracking is being considered to meet the construction schedule milestones, and special construction methods are being evaluated.
- The NIF general arrangement drawings for the NIF Laser and Target Area Building (LTAB) have been completed and are under configuration control. Design iterations continue for cost containment and reduction to assure that the design results in the minimum platform to achieve the requirements.
- An embedded laser-amplifier structure that offers important installation and operational advantages over the original conceptual design was developed and is the basis of the Title I design. This approach also simplifies utility interfaces above the amplifiers, which are now an integral part of the structure.
- Following an extensive technical and cost tradeoff evaluation, we selected flexible transmission lines for power conditioning over rigid lines and established a routing layout. Flexible lines result in easier installation and improved accessibility.
- We optimized the preamplifier module / preamplifier beam transport system layout to permit the output sensor packages to be located underneath the transport spatial filter for reduced cost and improved stability and operational accessibility. We completed the preamplifier module maintenance area layout and utility requirements.
- We have successfully resolved numerous conflicting requirements in the beam transport system and have established an end-to-end comprehensive design solution (see Fig. 1). Space allocations have been frozen for all laser bay and switchyard subsystems. Baseline switchyard and laser bay structures, which meet all stability, access and safety requirements, have been established and integrated with the other systems.
- We selected a hybrid concrete-steel construction early in the quarter for use on all the laser bay support structures. Detailed analysis confirmed the performance advantage of the hybrid structure over all-steel or all-concrete structures. The laser support structures have been integrated with all other subsystems.

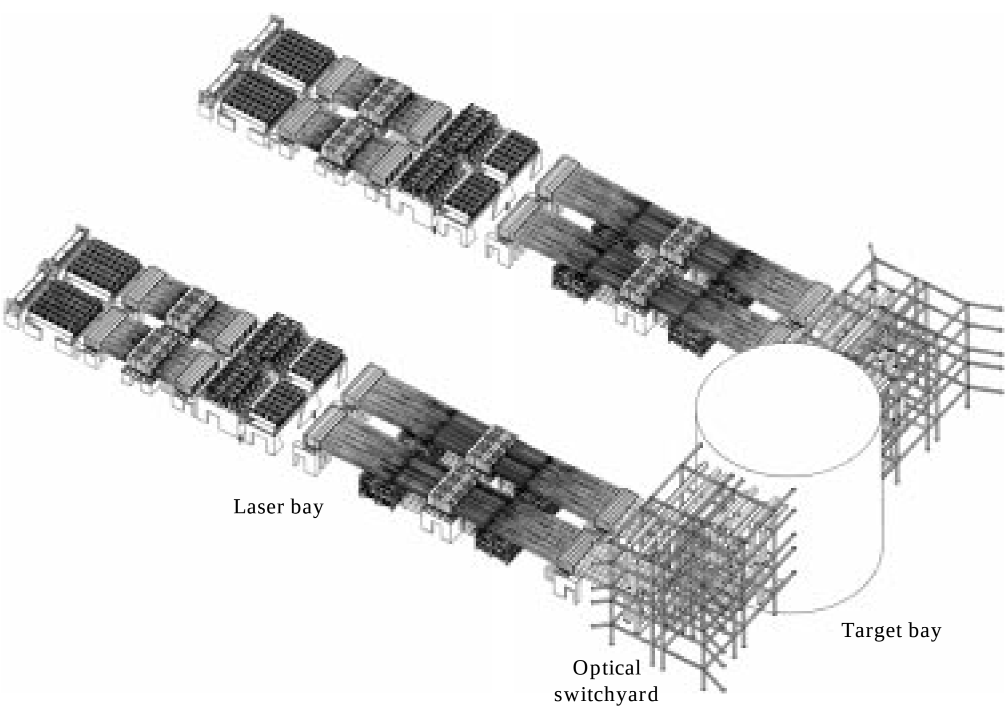


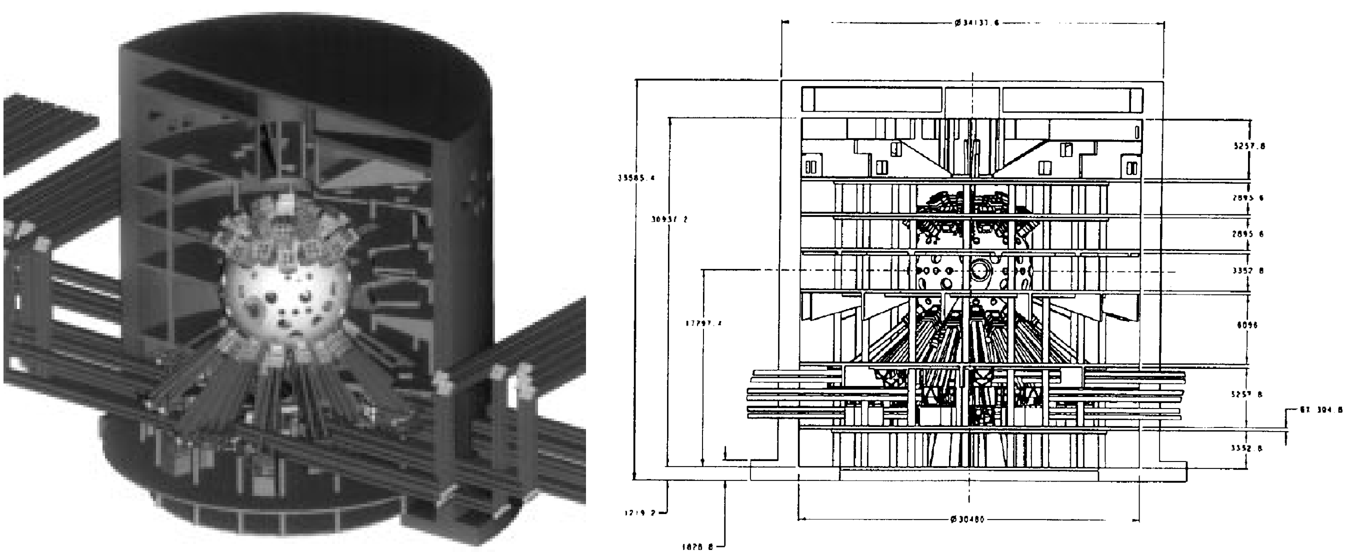
FIGURE 1. A comprehensive "end-to-end" integrated design has been developed. (40-00-0796-1771pb01)

- In collaboration with the ICF Core Science and Technology Program, a NIF prototype automatic-alignment loop, based on analysis of the beam profile and commercial Datacube processing system, was activated and is undergoing tests. CORBA and Ada95 software, which are planned for NIF use, are currently being tested in the front-end processors.
- We established the optical component layout for the main laser system. Title I optics sizes and thickness have been established, component spacing issues resolved, and configuration drawings generated for the laser optical train. We have completed individual system elements of the clear-aperture budget analysis, and integration and consistency checks are in progress.
- We resolved complicated design issues in the transport spatial filter, including optics locations, and paths for injection, alignment, diagnostics, wavefront control, and main beams. The optical stability has been improved by use of top-loading towers separate from the vacuum chamber.
- Major revisions to the target area design were carried out to incorporate the color separation filter in the final optics assembly. The beam transport codes were revised, the building configuration modified, new analytic models of the building developed, and the mirror supports redesigned and presented at the Mid-Title I Design Review.
- The finite-element integrated target-building / switchyard-structures model was refined to reflect the most recent design details (see Fig. 2). We continue to analyze structural / damping supports between the chamber / pedestal and target building floors. We delivered structural drawings of the target room floors, ribs, columns, and associated equipment loads to the LTAB Architecture / Engineering firm, Parsons, for their civil and structural analysis. Layouts of the target room floors and special equipment lasers were also delivered so that Parsons could model the area for the thermal analysis.
- Material flow studies have been effective in resolving LTAB corridor, doorway, and elevator size requirements. Development continued on requirements for optics transport and handling, and requirements for top-loading line replacable units were evaluated.
- The *Final Programmatic Environmental Impact Statement* is complete except for DOE comment resolution. The *Preliminary Safety Analysis Report* was completed as scheduled and submitted to DOE for concurrence review.

Twelve students from colleges and universities throughout the country, representing a number of technical disciplines, are employed by the NIF Project for the summer supporting the above activities.

Planning for the Title I Design Review is well under way. The Title I Design Review Plan was completed and released to Project personnel for their use in detailed planning of the remaining Title I work. The plan includes the overall objectives, organization, and schedules, as well as the agenda for the review meetings and contents of the Design Basis Books. The overall chairman of the review committee was selected and considerable progress made in identifying review committee members that will include DOE and external reviewers.

During the coming quarter, Title I documentation packages including design, cost, and schedule will be prepared, and the Title I Design Reviews will begin.



3-D CADD model

NIF drawing no. NM96-1.8.1-0000044-A

FIGURE 2. Engineering drawings are rapidly emerging from a comprehensive 3-D solid CADD model.   (40-00-0796-1633pb01)

NOVA/BEAMLET/NIF UPDATES JULY–SEPTEMBER 1996

G. Hermes

R. Speck

A. Clobes

Nova Operations

During this quarter, Nova Operations fired a total of 314 system shots resulting in 320 experiments. These experiments were distributed among ICF experiments, Defense Sciences experiments, X-Ray Laser experiments, Laser Sciences, and facility maintenance shots.

This is the final report for FY 1996. During the past year, Nova fired a total of 1192 system shots resulting in a total of 1263 experiments. There were 981 target experiments done in the 10-beam chamber and 86 experiments done in the 2-beam chamber. There were 110 experiments conducted in support of laser science work, including precision pointing, Petawatt system activation, and miscellaneous beam propagation experiments. We fired 85 calibration shots in support of routine and precision operations.

We have started implementing smoothing by spectral dispersion (SSD) on all 10 beamlines of Nova. Hardware for the preamplifier grading table and relay lens assemblies was installed this quarter. Experiments using 10-beam SSD are planned for FY 1997.

A conceptual design for a 4ω probe beam for the 10-beam chamber has been completed. This beamline will be created by a “pick-off” mirror installed into the center obscuration of beamline 8 in the switchyard. This subaperture, 1ω beam will be propagated to the 10-beam chamber, where it will be converted to 4ω and used as a target diagnostic probe beam. Actual installation of hardware will begin next quarter.

In continuing support of the Petawatt Project, the design of the Petawatt minichamber was completed and fabrication has started. This minichamber will be used during the initial Petawatt demonstration to measure system performance and beam focusability. Installation of the minichamber is planned for January 1997. The design of the parabolic mirror system that will be used for the Petawatt beam on the 10-beam chamber has been completed. The vacuum housing and mirror gimbals for the parabola are being fabricated. The vacuum system for the Petawatt compressor chamber was also installed and activated.

The Gated X-Ray Imager #5 (GXI 5), modified to use a charge-coupled device (CCD) readout, is continuing to be used as a secondary diagnostic to provide opportunities for shakedown and activation. The GXI is also being characterized off-line to evaluate its performance using the CCD readout as compared to film. The use of a CCD camera allows immediate viewing of data following a system shot.

Beamlet

During the fourth quarter of FY 1996, experiments done on Beamlet addressed the following issues:

- Correcting the wavefront for thermally driven gas turbulence in the amplifiers and the beam tubes.
- Measuring the 3ω conversion efficiency of the 34-cm output beam, the modulation of the 3ω near-field beam at the focus lens, and the 3ω focal-spot energy distribution.
- Conducting large-area damage tests of KDP at 3ω.
- Determining the performance of Beamlet with 20-ns pulses shaped like those required for indirect-drive ignition on NIF.
- Measuring the contrast ratio and beam modulation of the near-field beam input into the main amplifier.

The Beamlet control system was modified to allow the adaptive optics system to correct the beam wavefront up to one second before shot time (T-1s) to provide a capability to correct for gas turbulence effects in the beam path. To test this system, we fired shots to compare the 1ω spot size and beam brightness with and without the T-1s system. We observed that beam quality was improved with the T-1s system but that the improvement was smaller than expected. Because Beamlet has no active cooling system, we saw a more dominant effect from the accumulation of thermal distortion with repeated shots. Spot size and small-angle scatter increased substantially when repeated shots separated by 2-h intervals were fired. After the fourth shot, up to 15% of the energy was scattered outside of 33 μrad. The T-1s system has been used continuously since it was installed in early July.

We fired 53 shots in the 3ω campaign, 13 to activate and calibrate new diagnostics and 40 to obtain data on 3ω conversion efficiency, near-field beam modulation at the focus lens, and the 3ω focal-spot energy distribution. The new diagnostics included a 3ω dark-field imaging capability that allowed direct comparison of the scattered power fraction outside 33 μrad with corresponding 1ω measurements. The data shots were with short pulses of nominally 200-ps duration. In one series, the booster amplifier was unpumped to simulate the end of a NIF ignition pulse. In this series, we obtained 3ω power up to 2.3 TW with delta B in the booster amplifier up to 1.7 and with 200-μrad pinholes in both the cavity and transport spatial filters. We obtained up to 3.1 TW (delta B up to 2.0) with smaller 130-μrad cavity and 100-μrad transport filter pinholes. In a second series to reach powers similar to NIF SBSS performance requirements (3.5 TW of 3ω power in 1-ns pulses), we pumped the full 11-5 amplifier set. We achieved 3ω power up to 3.65 TW (corresponding to 4.6 TW for a NIF-sized beam) with 200-μrad pinholes in both the cavity and transport spatial filters at a 1ω drive power of 5.7 TW. Attempts to use smaller pinholes (130 / 100 μrad) with the pumped booster resulted in back reflections from the transport spatial filter that damaged the injection optics. This problem was not observed with the larger pinholes.

The large-aperture damage tests of KDP were the second series to test KDP. The samples were tested with 3-ns FWHM Gaussian pulses. During the series, Beamlet provided 3ω energies very close to those requested by the experimenters. Three samples were tested: a previously conditioned crystal, a new crystal, and a fast-growth crystal. All three samples were damaged below the expected fluence. In previous Beamlet campaigns, however, our 32-cm and 37-cm KDP / KD*P frequency-conversion crystals generated NIF output fluences on several shots without damage.

In the long-pulse campaign, we evaluated Beamlet's performance with typical pulse shapes proposed for indirect-drive ignition on NIF. The shots did not include frequency conversion but used absorbing glass as a beam dump in the frequency-conversion enclosure. We modified the pulse generation system to generate 20-ns shaped pulses. The modification in the master oscillator room (MOR) used a slow pulser to generate a long foot and used the prototype Arbitrary Wavefront Generator to provide a shaped main pulse. A cavity extension in the regenerative amplifier extended the gain window to 23 ns without affecting the stability and performance. We began the series with standard 200-μrad carbon pinholes in the transport spatial filter. We started at low energy and slowly increased the output energy up to slightly in excess of 13 kJ when evidence of pinhole closure was apparent. We changed the transport filter pinhole to a 200-μrad stainless steel conical pinhole designed to alleviate closure problems and repeated the energy ramp-up. With this design we reached in excess of 15 kJ, with no evidence of closure. Unfortunately, because of a failure in the bandwidth generation system, stimulated Brillouin scattering (SBS) generated in lens L3 caused the lens to fail and implode into the transport spatial filter, and the series had to be terminated. Rebuilding the spatial filter with new square lenses is expected to take 3 to 4 weeks.

In an attempt to resolve a discrepancy between the measured and calculated near-field profiles of the Beamlet output beam, we recorded near-field images at various planes in the preamplifier and injection optics. From these data we determined the spatial modulation at the input to the main amplifier (the calculations had assumed zero modulation at the input). Preliminary analysis now indicates that nearly all of the spatial intensity modulation is already present on the beam before input to the main amplifiers. When this is taken into account, the discrepancy between measured and calculated profiles at the output should be resolved.

NIF

This quarter, the engineering effort focused on narrowing the design options, further developing the specific designs, and updating the *Conceptual Design Report* (CDR) cost estimate based on extensive vendor quotations. The Conventional Facilities Title I Design, including the cost estimate, is now complete, and the Special Equipment Design and cost estimate 95% complete. The comprehensive Title I Design Review will begin early next quarter (October 8).

The Title I Design Reviews were delayed from the Title I Plan by one month following delay in the release of the *Programmatic Environmental Impact Statement for Stockpile Stewardship and Management* (PEIS) beyond the planned mid-September date. This time was used for value engineering of the designs and cost optimization to ensure that NIF is consistent with the minimum platform to achieve the Primary Criteria and Functional Requirements and the DOE Baseline Change Control Board Level 1 directions. The revised schedule completes the Title I Design in ten months, which is two months faster than the CDR schedule.

Planning for the Title I Design Review was completed, including completing the *Title I Design Review Plan,* which was released to Project personnel and used in detailed planning of the remaining Title I work. The plan includes the overall objectives, organization, and schedule, as well as an outline of the agenda for the review meetings and the contents of the Design Basis books. The overall Chairman of the Review Committee was selected, as well as committee members consisting of external and internal reviewers with significant expertise in their areas of review.

In parallel with the design effort, Title I cost and schedule estimates were developed. The cost estimate establishes the project cost baseline, is used as the basis for final design and construction estimation, and provides a high degree of confidence that the Project can be completed within the established baseline. The estimate provides budget outlay (BO) and budget authority (BA) profiles, a time-phased resource requirements plan, and a commitment profile. "Bottoms-up" estimates were generated by the lead / responsible engineers based on extensive vendor quotations. These estimates will be inputted to the NIF Planning system, which is an extension of the Business Planning system developed by LLNL and has been in use for over 10 years.

Following data input and verification, a Title I cost estimate contingency analysis based on a Monte Carlo simulation built from individual system risk assessment was developed. This analysis resulted in an overall contingency allocation for the Project. Planning for the DOE Independent Cost Estimate (ICE) Review has been completed and a kickoff meeting scheduled for the first week in October; ICE Review team members have been invited to the Title I Design Review.

In Manufacturing Engineering, manufacturing assessments were provided to the Special Equipment and lead engineers in support of the Title I design and costing effort. Over 270 detailed cost estimate validations were generated. A manufacturability report was drafted for the Title I Design Reviews.

In support of completion of Title I Design, and in preparation of Title II Design, upgrade and modification of the engineering support systems, including computer-aided design and drafting (CADD) and the Sherpa Product Data Management (PDM) systems, continued. An updated version of the PDM software was implemented and tested on a selected basis. This version, which is user-friendly and contains expanded help functions, reduces or eliminates the need for training. Conversion of the entire system to the updated version was delayed to ensure noninterference with completion of Title I Design. Classes on use of the NIF PDM system continue, and administrative support personnel are providing assistance to new and less experienced users.

PDM release procedures have been updated, and training on use of the PDM system continue to reflect the modifications to documents and design drawings control. The number of documents in the PDM system increases by about 50 per week, and by the end of the quarter there were over 600 documents in the system. Also, configuration management implementation continues. Training and implementation continue on drawing release, drawing revisions, and Engineering Change Request preparation.

The engineering effort focused this quarter on continuing design iterations to simplify the systems, reduce cost, and ensure a minimum platform system that meets the Primary Criteria and Functional Requirements and the Level 1 DOE Baseline Change Control Board actions. Extensive vendor quotes and refined cost estimates were collected, reviewed, and incorporated into the Title I cost estimate.

Specific Title I Design and supporting activities this past quarter include the following:

- Value Engineering of the LTAB and OAB was completed by Sverdrup to augment the continuing value engineering efforts. The study was completed and the results reviewed and incorporated into the design.
- Parsons was awarded the Project Labor Agreement Development and Oversight contract. The process for negotiating a Conventional Facilities Project Labor Agreement has been defined to reduce the schedule risks and cost impacts due to labor disputes during the Conventional Facilities construction.
- In cooperation with Conventional Facilities, issues associated with co-occupancy of special equipment installers and building constructors in the laser bay to expedite the schedule were resolved. An integrated plan for installing switchyard structures into the building erection sequence was established. Safety planning with the NIF Construction Manager for job site operations was begun.
- A combined target chamber / building construction schedule has been finalized. The schedule interfaces suggest that the chamber be built on the pedestal rather than constructed outside the target building and moved onto the pedestal.
- The Statement of Work for the target chamber fabrication was completed. Comments have been received and incorporated by NIF procurement, selection criteria were refined, and a Request for Proposal is scheduled for release early in FY 1997. Meetings with two potential target chamber fabricators were held, and both vendors confirmed the estimated fabrication time as well as choice of material.
- Changes to the target chamber diagnostic port locations were made based on input received from the Joint Committee for Target Diagnostics, consisting of members from the participating Laboratories. A port location interface control document (ICD) was completed and approved to document the information and assure that future changes are adequately reviewed and approved.

- Design iterations in the Final Optics Assembly continue. Individual 1 × 1 Integrated Optics Modules (IOMs) were selected to simplify the system and for ease of maintenance. Work was performed on a plan for the manufacturing of final optics cells by various methods, and visits to selected vendors for building a prototype final optics cell were prepared.
- Potential effects of distributed heat sources on the thermal stability of the optical systems were addressed by the NIF Thermal Working Group. This effort is closely coupled with the Parsons team performing the computational fluid dynamics analyses and members of the LLNL Thermal / Fluids Group.
- The Optical Configuration Layout drawing set, describing optical component position, orientation, and sizes, was completed. These drawings are an important source of interface information to the Special Equipment areas.
- To enable the initiation of long-lead optics procurement, several key drawings relating to fused silica material, lens finishing, and flat finishing have progressed to a near-final design state. Several significant analyses were documented. Among these were the clear-aperture budget and component damage-threshold requirements.
- All vendor optical cost studies were received, and NIF costs updated with the most current information available. Procurement strategy for optics has been completely defined, and the final version will be released with the Title I Design Basis Book.
- Significant cost savings were realized by production engineering of the amplifier demonstration AMPLAB components for use in NIF under a TRW Master Task Agreement work order. Concepts for amplifier cooling, support, and assembly hardware that meet NIF clean assembly requirements were completed.
- Several key amplifier power conditioning drawings were completed as part of Title I design, including the modified module layout and updated capacitor bay general arrangement. Life testing began at LLNL, in collaboration with the ICF Core Science and Technology Program, on prototype capacitors from two vendors and on the prototype module at Sandia National Laboratories-Albuquerque as part of the development program. Cost estimates were completed for key components, such as capacitors, and incorporated into the Title I cost rollup.
- The Software Requirement Specifications are essentially complete. Quality Level assessments for the Integrated Computer Control System were completed and approved. Remaining ICDs were completed, except for some minor revisions.
- Precision optical diagnostics design was improved with a simplified trombone and provisions for transport mirror maintenance. The midchain sensor design was completed, and requirements were completed for the target chamber diagnostic instrument manipulator.
- In Beam Transport, numerous design improvements that simplified the system and reduced costs were incorporated. They include simplified spatial filter beam tubes and reduced thickness of switchyard structure floor gratings, saving dead weight and increasing optical stability. Additional design optimization on the periscope structure reduced its weight, and use of component commonality reduced the part count in the switchyard and target bay mirror mounts.
- Utility layouts in the target bay and diagnostic building were completed. Revised cost estimates were generated and incorporated into the Title I estimate.
- Samples are arriving to validate parts of the NIF finishing process from Zygo and Tinsley. The first Phase 1 lens was received from Tinsley and is currently under evaluation.
- The draft *Start-up Plan* and a preliminary start-up schedule were completed. The second draft of the operations engineering schedule was completed for project inclusion and integration. The Title I Operations modeling effort has been completed and a report drafted.
- The NIF *Preliminary Safety Analysis Report* has been completed, and related DOE and institutional comments have been resolved. Institutional approval of the report by the Associate Directors for Laser Programs and Plant Operations has been received. DOE has concurred and will provide the *Safety Evaluation Report*, which gives final concurrence in early October.
- The PEIS has delayed the Notice of Availability to late October 1996 at the earliest. An analysis of delay impacts was prepared for DOE. The NIF *Technical Analysis* document, which includes justification and site comparisons, has been completed and is ready for publication.
- The environmental permit strategy was reviewed with DOE / OAK and DOE / HQ. All DOE comments to support the *Safety Evaluation Report* have been resolved.
- The *Quality Assurance Program Plan* (QAPP) was revised for Title II design, equipment procurement, and construction. Laboratory Project and DOE approval have been received. Eight Project procedures to implement the QAPP update were revised or prepared.

The Title I Design Reviews will be done time-phased, starting with the schedule critical path Conventional Facilities (including the Laser and Target Area Building, Optics Assembly Building, and site preparation) followed by three Special Equipment review segments. DOE actions, including determination by DP-1, with EH-1 concurrence, to proceed with limited Title II design concurrent with completion of the final PEIS and Record of Decision (ROD), will minimize the near-term adverse impact to the Project.

To maintain progress and keep the Project on schedule requires an ROD by mid-December 1996. Other activities that will be completed next quarter, leading to beginning of site preparation in mid-March 1997, include completing the ICE Review and preparing packages for the DOE Level 1 Baseline Change Control Board meeting in mid-December.